Semi-annual water column monitoring report: February - July 1998

Massachusetts Water Resources Authority

Environmental Quality Department
Report 1999-04

Semi-Annual Water Column Monitoring Report
February – July 1998

Submitted to

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EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) has collected water quality data in Massachusetts and Cape Cod Bays for the Harbor and Outfall Monitoring (HOM) Program since 1992. This monitoring is in support of the HOM Program mission to assess the potential environmental effects of the relocation of effluent discharge from Boston Harbor to Massachusetts Bay. The data are being collected to establish baseline water quality conditions and ultimately to provide the means to detect significant departure from that baseline. Battelle was contracted by MWRA to conduct baseline water quality surveys in Massachusetts and Cape Cod Bays during 1998 to 2000. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area in the vicinity of the outfall site (nearfield) and a low-frequency basis over an extended area throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (farfield). This semi-annual report summarizes water column monitoring results for the nine surveys conducted from February through July 1998.

The winter to spring transition in Massachusetts and Cape Cod Bays is usually characterized by a series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. For February to July 1998, however, conditions in the Bays were atypical marked by the delayed onset of seasonal stratification, lack of a winter/spring phytoplankton bloom, and nutrient replete conditions.

In the nearfield area, the water column had begun to stratify by early May and by mid-May there was a strong density gradient between the surface and bottom waters. In comparison to previous baseline monitoring years, the onset in stratification was delayed by 2 to 4 weeks in 1998. Due to the timing of surveys, seasonal stratification was not observed in the farfield until June. A significant rain event occurred prior to the June combined survey and, as a result of the rainfall and concomitant increase in runoff, low salinity surface waters were observed along the coast from Boston to Gloucester and into the northern and eastern portion of the nearfield. In these areas, the presence of low salinity surface waters served to intensify water column stratification.

Relative to other years, production at all three productivity stations was very low. No winter/spring phytoplankton bloom was observed during this sampling period. Generally, the nearfield area is characterized by the occurrence of a winter/spring phytoplankton bloom, while a gradual increase in areal production from winter to summer is more typical for Boston Harbor. In 1995 to 1997, the winter/spring phytoplankton bloom observed at the nearfield stations reached areal production values of 1000 to 4000 mg C m^{-2} d^{-1} and the blooms typically lasted 2-3 months. The absence of a winter/spring phytoplankton bloom during 1998 is being examined further and represents a major change in the seasonal productivity pattern relative to other years for the nearfield area.

The most striking observation from the nutrient data for the first half of 1998 was the lack of a strong spring draw down of nutrients in the nearfield. A combination of physical and biological factors contributed to the extended period of replete nutrients in the spring of 1998. Seasonal stratification did not develop until May, thus for much of the spring the water column was well mixed supplying nutrients to the surface waters. Additionally, storms in late February may have contributed not only to the instability of the water column, but also to increased terrestrial runoff of nutrients into the bays. Finally, areal productivity was relatively low throughout the region, there was no winter/spring diatom bloom, and the abundance of phytoplankton remained $< 10^6$ until May, thus biological nutrient uptake was relatively low. The combination of physical instability and biological inactivity resulted in elevated nutrient concentrations in the surface waters throughout most of the region from February to June.

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1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) has implemented a long-term Harbor and Outfall Monitoring (HOM) Program for Massachusetts and Cape Cod Bays. The objective of the HOM Program is to (1) test for compliance with NPDES permit requirements; (2) test whether the impact of the discharge on the environment is within the bounds projected by the SEIS; and (3) test whether change within the system exceeds the Contingency Plan thresholds. A detailed description of the monitoring and its rationale is provided in the Effluent Outfall Monitoring Plan developed for the baseline period and the post discharge monitoring plan (MWRA, 1997a).

To help establish the present water quality conditions with respect to nutrients, water properties, phytoplankton and zooplankton, and water-column respiration and productivity, the MWRA contracted with Battelle to conducted baseline water quality surveys in Massachusetts and Cape Cod Bays during 1998 to 2000. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area (nearfield) and a low-frequency basis for an extended area (farfield). The nearfield stations are located in the vicinity of the outfall site (Figure 1-1) and the farfield stations are located throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figure 1-2). The stations for the farfield surveys have been further separated into regional groupings according to geographic location to simplify regional data comparisons. This semi-annual report summarizes water column monitoring results for the nine surveys conducted from February through July 1998 (Table 1-1).

Table 1-1. Water Quality Surveys for WF981-WN989 February to July 1998

Survey #	Type of Survey	Survey Dates
WF981	Nearfield/Farfield	February 3-10
WF982	Nearfield/Farfield	February 27 – March 2
WN983	Nearfield	March 24
WF984	Nearfield/Farfield	March 31 – April 3
WN985	Nearfield	April 30, May 1
WN986	Nearfield	May 20
WF987	Nearfield/Farfield	June 16-22
WN988	Nearfield	July 8,13
WN989	Nearfield	July 23

Initial data summaries, along with specific field information, are available in individual survey reports submitted immediately following each survey. In addition, nutrient data reports (including calibration information, sensor and water chemistry data), plankton data reports, and productivity and respiration data reports are each submitted five times annually. Raw data summarized within this or any of the other reports are available from MWRA in hard copy and electronic formats.

1.2 Organization of the Semi-Annual Report

The scope of the semi-annual report is focused primarily towards providing an initial compilation of the water column data collected during the reporting period. Secondarily, integrated physical and biological results are discussed for key water column events. The report first provides a summary of the survey and laboratory methods (Section 2). The bulk of the report, as discussed in further detail below, presents results of water column data from the first nine surveys of 1998 (Sections 3-5). Finally, the major findings of the semi-annual period are summarized in Section 6.

Section 3 data are provided in data summary tables. The summary tables include the major numeric results of water column surveys in the semi-annual period by survey. A description of data selection, integration information, and summary statistics are included with that section.

Sections 4 (Results of Water Column Measurements) and 5 (Productivity, Respiration, and Plankton Results) include preliminary interpretation of the data including selected graphic representations of the horizontal and vertical distribution of water column parameters in both the farfield and nearfield. The horizontal distribution of physical parameters is presented through regional contour plots. The vertical distribution of water column parameters is presented using time-series plots of averaged surface and bottom water column parameters and along vertical transects in the survey area (Figure 1-3). The time-series plots utilize average values of the surface water sample (the "A" depth, as described in Section 3), and the bottom water collection depth (the "E" depth). Examining data trends along four farfield transects (Boston-Nearfield, Cohassett, Marshfield and Nearfield-Marshfield), and one nearfield transect, allows three-dimensional analysis of water column conditions during each survey. One offshore transect (Boundary) enables analysis of results in the outer most boundary of the survey area during farfield surveys.

Results of water column physical, nutrient, chlorophyll, and dissolved oxygen data are provided in Section 4. Survey results were organized according to the physical characteristics of the water column during the semi-annual period. The timing of water column vertical stratification, and the physical and biological status of the water column during stratification, significantly effects the temporal response of the water quality parameters which provide a major focus for assessing effects of the outfall. This report describes the horizontal and vertical characterization of the water column during pre-stratification stage (WF981 – WF984), and then further delineated processes occurring during the early stratification stage (WN985 – WN989). Time-series data are commonly provided for the entire semi-annual period for clarity and context of the data presentation.

Productivity, respiration, and plankton measurements, along with corresponding discussion of chlorophyll and dissolved oxygen results, are provided in Section 5. Discussion of the biological processes and trends during the semi-annual period is included in this section. A summary of the major water column events and unusual features of the semi-annual period is presented in Section 6. References are provided in Section 7.

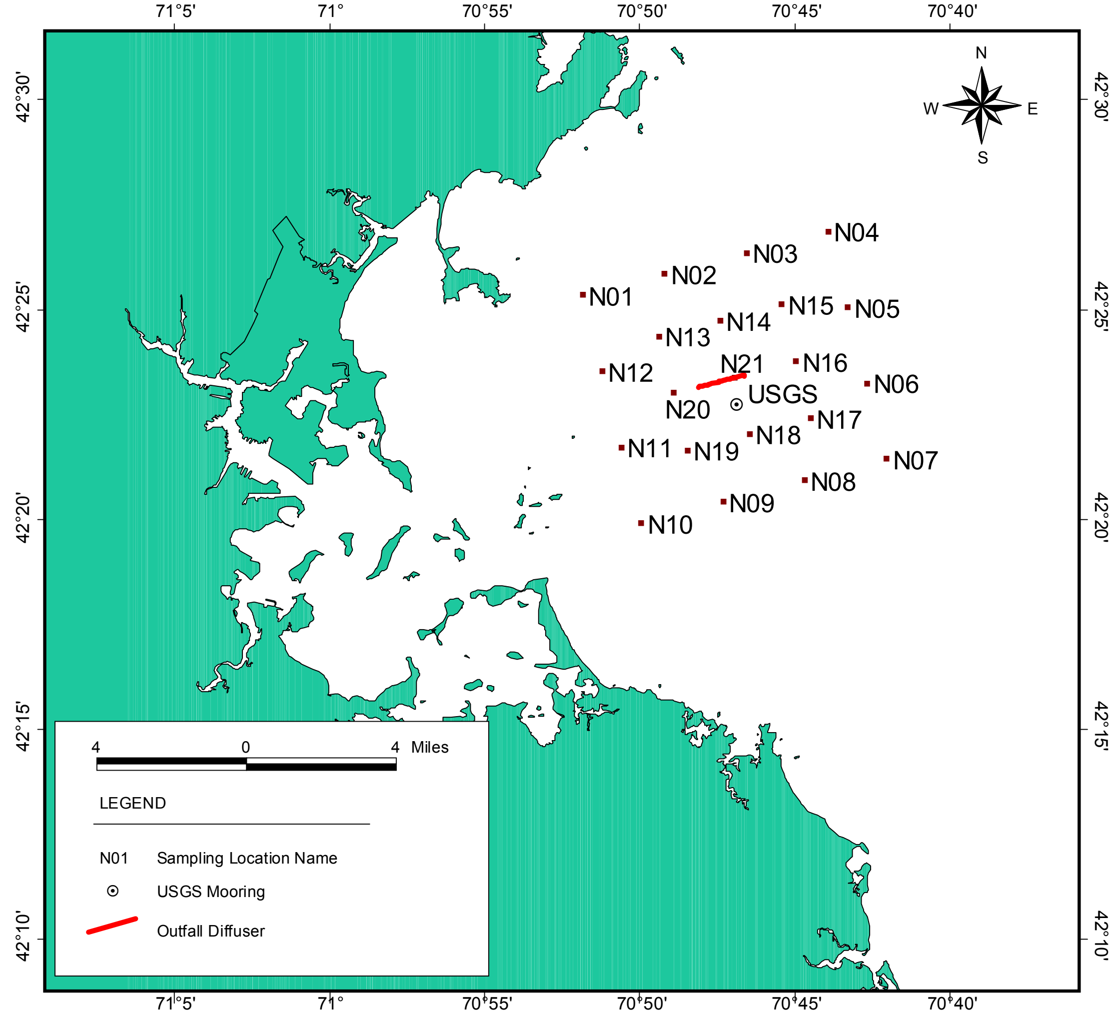


Figure 1-1. Locations of MWRA Offshore Outfall, Nearfield Stations and USGS Mooring

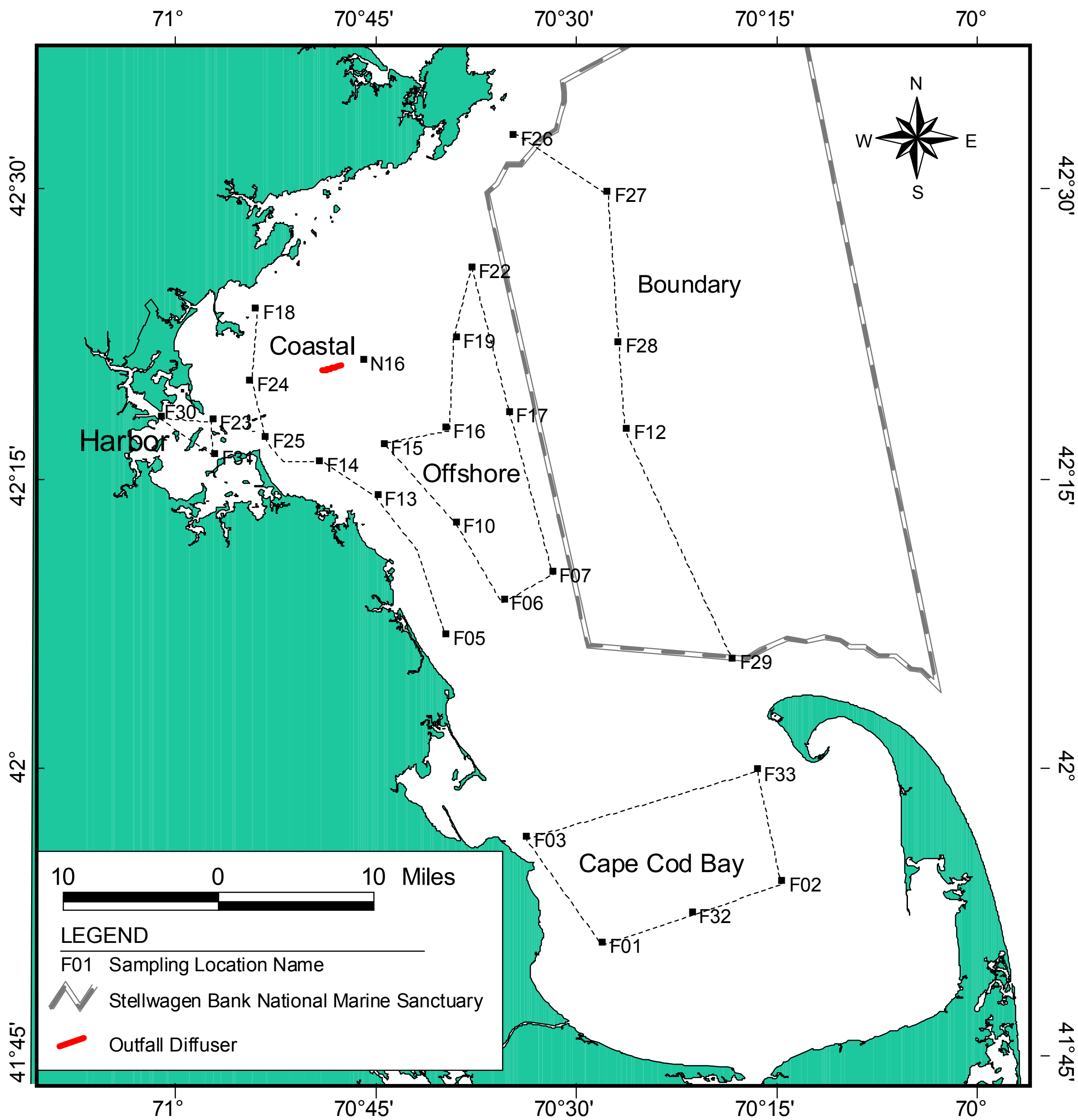


Figure 1-2. Locations of Farfield Stations

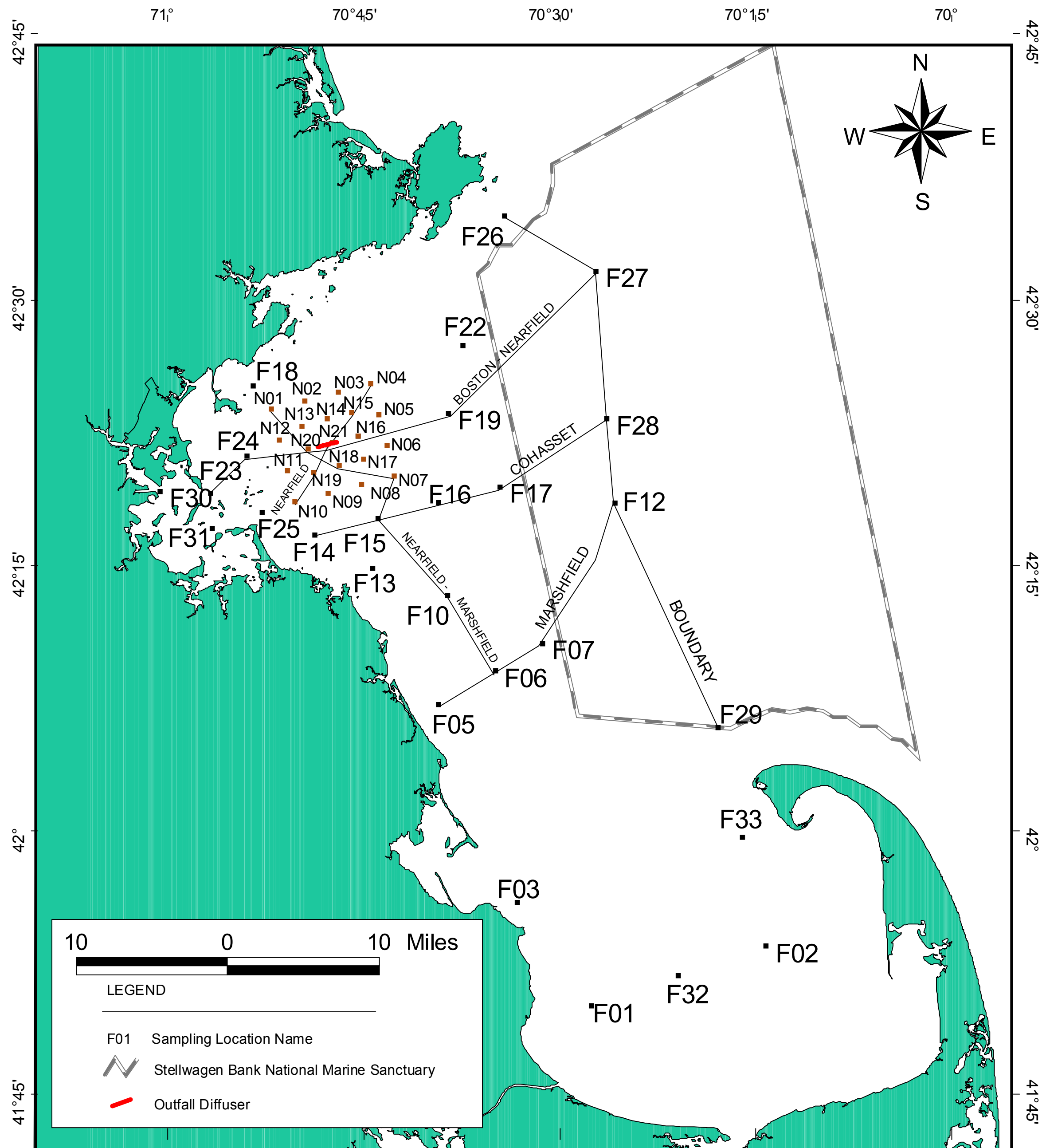


Figure 1-3. Location of Stations Selected for Vertical Transect Graphics Showing Transect Name

2.0 METHODS

This section describes general methods of data collection and sampling for the first nine water column monitoring surveys of 1998. Section 2.1 describes data collection methods, including survey dates, sampling platforms, and analyses performed. Section 2.2 describes the sampling schema undertaken, and Section 2.3 details specific operations for the first 1998 semi-annual period. Specific details of field sampling and analytical procedures, laboratory sample processing and analysis, sample handling and custody, calibration and preventative maintenance, documentation, data evaluation, and data quality procedures are discussed in the Water Quality Monitoring CW/QAPP (Albro *et al*., 1998). Details on productivity sampling procedures and analytical methods are also available in Appendix A.

2.1 Data Collection

The farfield and nearfield water quality surveys for 1998 represent a continuation of the baseline water quality monitoring conducted from 1992 – 1997. The monitoring program has been improved over the years as more data have been collected and evaluated. For 1998, two farfield stations (F32 and F33) were added in Cape Cod Bay during the first three farfield surveys of the year. These two stations were sampled for zooplankton and hydrographic (CTD) properties.

Water quality data for this report were collected from the sampling platforms *R/V Haley's Comet II* (now named *R/V Aquamonitor*), *M/V Seabreeze,* and *F/V Isabel S.* Continuous vertical profiles of the water column and discrete water samples were collected using a CTD/Go-Flo Bottle Rosette system. This system includes a deck unit to control the system, display *in situ* data, and store the data, and an underwater unit comprised of several environmental sensors, including conductivity, temperature, depth, dissolved oxygen, transmissometry, irradiance, and fluorescence. These measurements were obtained at each station by deploying the CTD; in general, one cast was made at each station. Water column profile data were collected during the downcast, and water samples were collected during the upcast by closing the Go-Flo bottles at selected depths, as discussed below.

Water samples were collected at five depths at each station, except at stations F30, F31, F32, and F33. Stations F30 and F31 are shallow and require only three depths while only zooplankton samples are collected at F32 and F33. These depths were selected during CTD deployment based on positions relative to the pycnocline or subsurface chlorophyll maximum. The bottom depth (within 5 meters of the sea floor) and the surface depth (within 3 meters of the water surface) of each cast remained constant and the mid-bottom, middle and mid-surface depths were selected to represent any variability in the water column. In general, the selected middle depth corresponded with the chlorophyll maximum and or pycnocline. When the chlorophyll maximum occurred significantly below or above the middle depth, the mid-bottom or mid-surface sampling event was substituted with the mid-depth sampling event and the "mid-depth" sample was collected within the maximum. In essence, the "mid-depth" sample in these instances was not collected from the middle depth, but shallower or deeper in the water column in order to capture the chlorophyll maximum layer. These nomenclature semantics result from a combination of field logistics and scientific relevance. In the field, the switching of the "mid-depth" sample with the mid-surface or mid-bottom was transparent to everyone except the NAVSAM operator who observed the subsurface chlorophyll structure and marked the events. The samples were processed in a consistent manner and a more comprehensive set of analyses were conducted for the surface, mid-depth/chlorophyll maximum, and bottom samples.

Samples from each depth at each station were collected by subsampling from the Go-Flo bottles into the appropriate sample container. Analyses performed on the water samples are summarized in Table 2-1. Samples for dissolved inorganic nutrients (DIN), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and phosphorus (TDP), particulate organic carbon (POC) and nitrogen

(PON), biogenic silica, particulate phosphorus (PP), chlorophyll *a* and phaeopigments, total suspended solids (TSS), urea, and phytoplankton (screened and rapid assessment) were filtered and preserved immediately after obtaining water from the appropriate Go-Flo bottles. Whole water phytoplankton samples (unfiltered) were obtained directly from the Go-Flo bottles and immediately preserved. Zooplankton samples were obtained by deploying a zooplankton net overboard and making an oblique tow of the upper two-thirds of the water column but with a maximum tow depth of 30 meters. Productivity samples were collected from the Go-Flo bottles, stored on ice and transferred to University of Rhode Island (URI) employees. Incubation was started no more that six hours after initial water collection at URI's laboratory. Respiration samples were collected from the Go-Flo bottles at four stations (F19, F23, N04, and N18). Incubations of the dark bottles were started within 30 minutes of sample collection. The dark bottle samples were maintained at a temperature within 2°C of the collection temperature for five to seven days until analysis.

2.2 Sampling Schema

A synopsis of the sampling schema for the analyses described above is outlined in Tables 2-1, 2-2, and 2-3. Station designations were assigned according to the type of analyses performed at that station (see Table 2-1). Productivity and respiration analyses were also conducted at certain stations and represented by the letters P and R, respectively. Table 2-1 lists the different analyses performed at each station. Tables 2-2 (nearfield stations) and 2-3 (farfield stations) provide the station name and type, and show the analyses performed at each depth. Station N16 is considered both a nearfield station (where it is designated as type A) and a farfield station (where it is designated a type D). Stations F32 and F33 are occupied during the first three farfield surveys of each year and collect zooplankton samples and hydrocast data only (designated as type Z).

Table 2-1. Station Types and Numbers (Five Depths Collected Unless Otherwise Noted)

Station Type	**A**	**D**	**E**	**F**	**G[1]**	**P**	**R**	**Z**
Number of Stations	**5**	**8**	**26**	**3**	**2**	**3**	**4**	**2**
Analysis Type								
Dissolved inorganic nutrients (NH_4, NO_3, NO_2, PO_4, and SiO_4)	•	•	•	•	•	•		
Other nutrients (DOC, TDN, TDP, PC, PN, PP, Biogenic Si)[1]	•	•			•	•		
Chlorophyll [1]	•	•			•	•		
Total suspended solids [1]	•	•			•	•		
Dissolved oxygen	•	•		•	•	•		
Phytoplankton, urea [2]		•			•	•		
Zooplankton[3]		•			•	•		•
Respiration [1]						•	•	
Productivity, DIN						•		

[1]Samples collected at three depths (bottom, mid-depth, and surface)

[2]Samples collected at two depths (mid-depth and surface)

[3]Samples collected at the surface

2.3 Operations Summary

Changes in the 1998 sampling schema from prior monitoring years included the addition of two new zooplankton stations in Cape Cod Bay, sampled during the first three farfield surveys (WF981, WF982, and WF984) and collecting special phytoplankton samples for methodological comparisons and comparability assessments. Field operations for water column sampling and analysis during the first semi-annual period were conducted as described above. Deviations from the CW/QAPP for nearfield surveys WN983, WN986, and WN989 had no effect on the data. Principal deviations for surveys WF981, WF982, WF984, WN985, WF987, and WN988 are described below. For additional information about a specific survey, the individual survey reports may be consulted.

During the farfield/nearfield survey in early February (WF981), the two fluorometers on the BOSS failed. The field crew collected extra chlorophyll samples at Stations F15, F16, F17, F19, F22, F26, and F03 to manually measure the chlorophyll concentrations at these stations. Both instruments were sent to the manufacturer for repair. Surface irradiance was not collected on February 3rd and 4th due to oversight when replacing a damaged hard drive. At station F22, a mid-surface sample was not collected due to a malfunctioning Go-Flo bottle, thus one dissolved inorganic nutrient sample was not collected.

Several DO samples were not measured during farfield/nearfield survey WF982 due to laboratory accidents (F02 Bottom and Surface, F23 Mid-bottom and Surface, and N10 Bottom (Rep2)). Additionally, during WN982, a minor shipboard ^{14}C accident resulted in the loss of the productivity data from this survey. As a result of this accident, Battelle has decided to incubate on shore in the future.

During the farfield/nearfield survey in April (WF984), the dissolved inorganic nutrient (DIN) protocol was changed with regard to the type of filter used for processing. Glass fiber filters (GF/F) were changed to Nuclepore filters to prevent possible contamination of silicate. Also on April 1st, no triplicate QC samples for dissolved oxygen were collected at the first and last stations of the day.

Due to a last minute schedule shift for nearfield survey WN985, a qualified whale watcher was not on board during the survey. The Chief Scientist and Captain of the vessel tried to maintain overlapping watches but mammals may be under-reported for this survey. Even though a whale watcher was not on board, the Captain conducted vessel operations within all Massachusetts state and federal guidelines for the avoidance of collision with right whales.

During farfield/nearfield survey WF987, triplicate QC samples for dissolved oxygen were not collected at the first and last stations on the first two days. Respiration samples were collected at all of the appropriate locations but only the station F19 bottom and mid-depth samples remained at the appropriate temperature due to electrical power interruptions to the incubators. The F19 samples were the only samples analyzed.

On July 8th, four stations (N04, N15, N21, and N18) were sampled for nearfield survey WN988 prior to experiencing problems with the electrical cable to the CTD. Productivity samples were shipped to the University of Rhode Island laboratory for analysis. Due to the loss of electrical power for the sample storage freezer, the nutrient samples were compromised. Following discussions with MWRA and the Battelle Program Manager it was determined that the nutrient samples from the four stations sampled on July 8th would be analyzed to support the primary productivity. The data will be entered into the database and flagged as appropriate to separate it from the standard data reductions and procedures. It was also determined that the zooplankton samples from July 8th, would be archived in case analysis was determined to be necessary. In consultation with MWRA scientists, it was determined that all four stations would be revisited on July 13th and that samples would be collected for the designated nutrient, phytoplankton, zooplankton, and respiration parameters. Thus, the data for productivity are not synoptic with the nutrient, phytoplankton, and respiration data. This should not adversely effect the interpretation of the various data sets.

Table 2-2. Nearfield Water Column Sampling Plan (3 Pages)

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.6	0.3	0.5	1	1	4	1	4	1	0.1	1	1	1
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N01	30	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N02	40	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N03	44	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2							6	1	1
			2_Mid-Bottom	4.5	1	1						1		1							1	1
N04	50	D+	3_Mid-Depth	22.1	2	2	1	1	2	2	2	2	2			1	1		1	6	1	1
		R+	4_Mid-Surface	4.5	1	1						1		1							1	1
		P	5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N05	55	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N06	52	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	10.5	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
N07	52	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	10.5	2	1	1	1	2	2	2	1	2	3								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N08	35	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N09	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N10	25	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N11	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N12	26	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N13	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N14	34	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N15	42	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N16	40	A	3_Mid-Depth	10.2	2	2	2	2	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N17	36	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2							6	1	1
		D+	2_Mid-Bottom	4.5	1	1						1		1							1	1
N18	30	R+	3_Mid-Depth	26.1	3	1	1	1	2	2	2	2	2		1	1	1		1	6	1	2
		P	4_Mid-Surface	4.5	1	1						1		1							1	1
			5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N19	24	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N20	32	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N21	34	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
				Totals		111	22	22	42	42	42	42	42	33	1	4	4	2	4	36	10	11
Blanks A									1	1	1	1	1									

Table 2-3. Farfield Water Column Sampling Plan (3 Pages)

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.3	0.3	0.5	1	1	0	1	4	1	0.1	1	1	1
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F01	27	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F02	33	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F03	17	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F05	18	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F06	35	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F07	54	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F10	30	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	4	1	1								1								
			2_Mid-Bottom	2	1	1								1								
F12	90	F	3_Mid-Depth	2	1	1								1								
			4_Mid-Surface	2	1	1								1								
			5_Surface	4	1	1								1	1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F13	25	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorus	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F14	20	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F15	39	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F16	60	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F17	78	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F18	24	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7	2	1														6		
			2_Mid-Bottom	2	1	1								1								
F19	81	F+R	3_Mid-Depth	7	2	1														6		
			4_Mid-Surface	2	1	1								1								
			5_Surface	7	2	1									1					6		
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F22	80	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	18	3	1	1	1	2	2	2	1	2							6	1	1
			2_Mid-Bottom	8.5	1	1						1		1							1	2
F23	25	D+R+P	3_Mid-Depth	24	3	1	1	1	2	2	2	2	2			1	1		1	6	1	1
			4_Mid-Surface	7.5	1	1						1		1							1	1
			5_Surface	23	3	1	1	1	2	2	2	1	2		1	1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F24	20	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F25	15	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F26	56	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F27	08	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F28	33	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	2	1	1								1								
			2_Mid-Bottom	2	1	1								1								
F29	66	F	3_Mid-Depth	2	1	1								1								
			4_Mid-Surface	2	1	1								1								
			5_Surface	2	1	1								1	1							
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F30	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F31	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
F32	30	Z	5_Surface												1							
			6_Net Tow															1				
F33	30	Z	5_Surface												1							
			6_Net Tow															1				
			1_Bottom	8.1	2	1	2	2	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N16	40	D	3_Mid-Depth	15	2	2	2	2	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
					otals	132	35	35	66	66	66	62	66	76	28	22	22	13	22	36	5	6
			Blanks B						1	1	1	1	1									
			Blanks C						1	1	1	1	1									
			Blanks D						1	1	1	1	1									

3.0 DATA SUMMARY PRESENTATION

Data from each survey were compiled from the final HOM Program 1998 database and organized to facilitate regional comparisons between surveys, and to allow a quick evaluation of results for evaluating monitoring thresholds (Table 3-1 Method Detection Limits, Survey Data Tables 3-2 through 3-10). Each table provides summary data from one survey. A discussion of which parameters were selected, how the data were grouped and integrated, and the assumptions behind the calculation of statistical values (average, minimum, and maximum), is provided below. Individual data summarized in this report are available from MWRA either in hard copy or electronic format.

The spatial pattern of data summary follows the sample design over major geographic areas of interest in Massachusetts Bay, Cape Cod Bay, and Boston Harbor (Section 3.1). Compilation of data both horizontally by region and vertically over the entire water column was conducted to provide an efficient way of assessing the status of the regions during a particular survey. Maximum and minimum values are provided because of the need to assess extremes of pre-outfall conditions relative to criteria being developed for contingency planning purposes (MWRA, 1997).

Regional compilations of nutrient and biological water column data were conducted first by averaging individual laboratory replicates, followed by field duplicates, and then by station visit within a survey. Prior to regional compilation of the sensor data, the results were averaged by station visit. Significant figures for average values were selected based on precision of the specific data set. Detailed considerations for individual data sets are provided in the sections below.

3.1 Defined Geographic Areas

The primary partitioning of data is between the nearfield and farfield stations (Figures 1-1 and 1-2). Farfield data were additionally segmented into five geographic areas: stations in Boston Harbor (F23, F30, and F31), coastal stations (F05, F13, F14, F18, F24, F25), offshore stations (F06, F07, F10, F15, F16, F17, F19, and F22), boundary region stations (F12, F26, F27, F28, F29), and Cape Cod Bay stations (F01, F02, and F03; and F32 and F33 as appropriate). These regions are shown in Figure 1-2.

The data summary tables include data derived from all of the station data collected in each region. Average, maximum, and minimum values are reported from the cumulative horizontal and vertical dataset as described for each data type below.

3.2 Sensor Data

Six CTD profile parameters provided in the data summary tables include: temperature, salinity, density (σ_t), fluorescence (chlorophyll a), transmissivity, and dissolved oxygen (DO) concentration. Statistical parameters (maximum, minimum, and average) were calculated from the upcast sensor readings collected at five depths through the water column (defined as A-E). The five depth values, rather than the entire set of profile data, were selected to reduce the statistical weighting of deep water data at the offshore and boundary stations. Generally, the samples were collected in an even depth-distributed pattern. The mid-depth sample (C) was typically located at the subsurface fluorescence (chlorophyll) peak in the water column, depending on the relative depth of the chlorophyll maximum. Details of the collection, calibration, and processing of CTD data are available in the Water Column Monitoring CW/QAPP (Albro *et al*., 1998), and are summarized in Section 2.

Following standard oceanographic practice, patterns of variability in water density are described using the derived parameter sigma-t ($\sigma_{t,}$), which is calculated by subtracting 1,000 kg/m^3 from the recorded density. During this semi-annual period, density varied from 1016.3 to 1027.4, meaning σ_t varied from 16.3 to 27.4.

Fluorescence data were calibrated using concomitant extracted chlorophyll *a* data from discrete water samples collected at a subset of the stations (see CW/QAPP or Tables 2-1, 2-2, 2-3). The calibrated fluorescence sensor values were used for all discussions of chlorophyll in this report. The concentrations of phaeopigments are included in the summary data tables as part of the nutrient parameters.

In addition to DO concentration, the derived percent saturation was also provided. Percent saturation was calculated prior to averaging station visits from the potential saturation value of the water (a function of the physical properties of the water) and the calibrated DO concentration (see CW/QAPP).

Finally, the derived beam attenuation coefficient from the transmissometer ("transmittance") was provided on the summary tables. Beam attenuation is calculated from the natural logorithim of the ratio of light transmission relative to the initial light incidence, over the transmissometer path length, and is provided in units of m^{-1}.

3.3 Nutrients

Analytical results for dissolved and particulate nutrient concentrations were extracted from the HOM database, and include: ammonia (NH_4), nitrite (NO_2), nitrate + nitrite (NO_3+NO_2), phosphate (PO_4), silicate (SiO_4), biogenic silica (BSI), dissolved and particulate organic carbon (DOC and POC), total dissolved and particulate organic nitrogen (TDN and PON), total dissolved and particulate phosphorous (TDP and PP), and urea. Total suspended solids (TSS) data are provided as a baseline for total particulate matter in the water column. Dissolved inorganic nutrients (NH_4, NO_2, No_3+NO_2, PO_4, and SiO_4) were measured from water samples collected from each of the five (A-E) depths during CTD casts. The dissolved organic and particulate constituents were measured from water samples collected from the surface (A), mid-depth (C), and bottom (E) sampling depths (see Tables 2-1, 2-2, and 2-3 for specific sampling depths and stations).

3.4 Biological Water Column Parameters

Four productivity parameters have been presented in the data summary tables. Areal production, which is determined by integrating the measured productivity over the photic zone, and chlorophyll-specific areal production is included for the productivity stations (F23 representing the harbor, and N04 and N18, representing the nearfield). Because areal production is already depth-integrated, averages were calculated only among productivity stations for the two regions sampled. The derived parameters α ($gC[gChla]^{-1}h^{-1}[\mu Em^{-2}s^{-1}]^{-1}$) and Pmax ($gC[gChla]^{-1}h^{-1}$) are also included. The productivity parameters are discussed in detail in Appendix A.

Respiration rates were averaged over the respiration stations (the same harbor and nearfield stations as productivity, and additionally one offshore station [F19]), and over the three water column depths sampled (surface, mid- and bottom). The respiration samples were collected concurrently with the productivity samples. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al*., 1998).

3.5 Plankton

Plankton results were extracted from the HOM database and include whole water phytoplankton, screened phytoplankton, and zooplankton. Phytoplankton samples were collected for whole-water and screened measurements during the water column CTD casts at the surface (A) and mid-depth (C) sampling events. As discussed in Section 2.1, when a subsurface chlorophyll maximum is observed, the mid-depth sampling event is associated with this layer. The screened phytoplankton samples were filtered through 20-µm Nitrex mesh to retain and concentrate larger dinoflagellate species. Zooplankton samples were collected by oblique tows using a 102-µm mesh at all plankton stations. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al*., 1998).

Final plankton values were derived from each station by first averaging analytical replicates, then averaging station visits. Regional results were summarized for total phytoplankton, total centric diatoms, nuisance algae (*Alexandrium tamarense, Phaeocystis pouchetii,* and *Pseudo-nitzschia pungens*), and total zooplankton (Tables 3-2 through 3-10).

Results for total phytoplankton and centric diatoms reported in Tables 3-1 through 3-10 are restricted to whole water surface samples. Results of the nuisance species *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* include the maximum of both whole water and screened analyses, at both the surface and mid-depth. Although the size and shape of both taxa might allow them to pass through the Nitex screen, both have colonial forms that in low densities might be overlooked in the whole-water samples. For *Alexandrium tamarense*, only the screened samples were reported.

3.6 Additional Data

Two additional data sources were utilized during interpretation of HOM Program semi-annual water column data. Temperature and chlorophyll a satellite images collected near survey dates were preliminarily interpreted for evidence of surface water events, including intrusions of surface water masses from the Gulf of Maine and upwelling (Appendix I). U.S. Geological Service continuous monitoring data, collected from a mooring located between nearfield stations N21 and N18 (Figure 1-1). Hourly temperature and salinity data from the mid-depth (~20 m below surface) and near-bottom (1 m above bottom) are plotted in Figure 3-1. Chlorophyll a data from the USGS Wetlab sensor from the mid-depth (~20 m below surface) are plotted in Figure 3-2.

Table 3-1 Method Detection Limits

Analysis	MDL
Dissolved ammonia (NH_4)	0.02 µM
Dissolved inorganic nitrate (NO_3)	0.01 µM
Dissolved inorganic nitrite (NO_2)	0.01 µM
Dissolved inorganic phosphorus (PO_4)	0.01 µM
Dissolved inorganic silicate (SIO_4)	0.02 µM
Dissolved organic carbon (DOC)	20 µM
Total dissolved nitrogen (TDN)	1.43 µM
Total dissolved phosphorus (TDP)	0.04 µM
Particulate carbon (POC)	5.27 µM
Particulate nitrogen (PON)	0.75 µM
Particulate phosphorus (PARTP)	0.04 µM
Biogenic silica (BIOSI)	0.32 µM
Urea	0.2 µM
Chlorophyll *a* and phaeophytin (EDL)	0.036 µg L^{-1}
Total suspended solids (TSS)	0.1 mg L^{-1}

Table 3-2. Combined Farfield/Nearfield Survey WF981 (Feb 98) Data Summary

		Farfield								
Region		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	3.41	5.44	4.41	3.05	3.94	3.46	2.87	3.61	3.23
Salinity	PSU	30.8	32.5	32.1	31.5	32.0	31.8	31.0	31.9	31.6
Sigma _T		24.5	25.7	25.4	25.1	25.4	25.3	24.7	25.4	25.1
Beam Attenuation	m-1	0.57	1.35	0.85	0.83	2.72	1.58	1.58	3.90	2.66
DO Concentration	mg L-1	9.31	11.36	10.11	10.51	11.87	11.25	10.69	11.74	11.25
DO Saturation	PCT	91.4	104.8	96.4	99.2	109.9	104.5	99.4	109.6	103.9
Fluorescence	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chlorophyll a	ug L-1	0.15	1.05	0.59	0.20	1.29	0.64	0.10	1.75	0.58
Phaeopigment	ug L-1	0.07	0.53	0.25	0.09	0.65	0.41	0.22	1.44	0.73
Nutrients										
NH4	uM	0.11	1.28	0.48	1.19	2.34	1.71	0.48	6.70	2.67
NO2	uM	0.10	0.22	0.16	0.01	0.24	0.16	0.15	0.36	0.22
NO2+NO3	uM	6.38	9.03	7.90	0.48	9.26	6.78	7.16	10.49	8.70
PO4	uM	0.71	0.90	0.83	0.09	0.91	0.79	0.72	0.98	0.87
SIO4	uM	5.89	14.02	9.96	0.61	11.52	8.65	9.85	14.27	11.61
BIOSI	uM	0.50	1.50	1.00	1.50	2.80	2.12	2.50	6.10	4.64
DOC	uM	102.0	125.3	113.7	119.5	182.4	142.0	114.7	142.4	126.1
PARTP	uM	0.05	0.10	0.07	0.11	0.34	0.19	0.14	0.41	0.31
POC	uM	3.61	9.92	6.09	8.92	18.92	13.21	14.50	25.50	20.03
PON	uM	0.09	0.76	0.33	1.74	2.84	2.29	1.61	2.75	2.23
TDN	uM	15.7	16.2	16.0	13.6	39.1	22.1	20.5	31.4	24.0
TDP	uM	0.99	1.04	1.02	0.94	1.15	1.06	1.01	1.30	1.16
TSS	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.90	0.57
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM hr-1									
Plankton										
Total Phytoplankton	E6CELLS L-1	0.173	0.374		0.321	0.887		0.329	0.674	
Centric diatoms	E6CELLS L-1	0.008	0.027		0.011	0.516		0.034	0.049	
Alexandrium tamarense	CELLS L-1	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	ND	ND		0.001	0.001		ND	ND	
Total Zooplankton	ind m-3	9930.5	9930.5		12043.6	56202.3		6308.8	8322.1	

NA - Data not available due to sample loss

ND - Not detected in the sample

Table 3-2. Combined Farfield/Nearfield Survey WF981 (Feb 98) Data Summary (continued)

Region		Harbor			Offshore			Nearfield		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	2.66	4.06	2.94	3.43	4.87	4.15	2.99	4.66	3.51
Salinity	PSU	30.4	31.5	31.0	31.6	32.4	32.1	31.3	32.3	31.8
Sigma _T		24.3	25.1	24.7	25.1	25.6	25.5	25.0	25.6	25.3
Beam Attenuation	m-1	1.73	4.21	3.36	0.69	1.99	0.96	0.87	2.81	1.39
DO Concentration	mg L-1	9.33	11.28	10.63	10.04	11.90	10.91	6.95	11.75	10.75
DO Saturation	PCT	87.9	102.7	97.1	96.9	111.3	103.4	66.2	109.2	100.1
Fluorescence	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chlorophyll a	ug L-1	0.13	0.96	0.56	0.01	0.98	0.33	0.01	1.41	0.50
Phaeopigment	ug L-1	0.06	1.53	0.95	0.02	3.50	0.28	0.02	0.80	0.35
Nutrients										
NH4	uM	8.14	13.66	10.93	0.15	1.04	0.52	0.15	6.08	0.88
NO2	uM	0.31	0.54	0.42	0.14	0.20	0.17	0.01	0.35	0.18
NO2+NO3	uM	9.88	13.81	10.92	6.68	8.02	7.71	7.22	10.15	8.20
PO4	uM	0.98	1.28	1.11	0.74	0.92	0.86	0.69	1.07	0.81
SIO4	uM	13.68	24.63	16.36	8.56	11.35	9.79	8.57	25.74	10.40
BIOSI	uM	1.90	6.50	4.47	1.10	1.40	1.23	0.40	3.60	2.04
DOC	uM	117.6	208.5	153.8	114.1	118.7	116.4	97.6	153.4	122.5
PARTP	uM	0.26	0.60	0.44	0.05	0.08	0.07	0.05	0.72	0.15
POC	uM	14.33	47.67	32.78	7.48	10.83	8.67	3.33	22.42	11.68
PON	uM	1.91	5.13	3.79	1.66	2.22	2.01	0.21	2.89	1.58
TDN	uM	29.5	40.2	34.4	17.1	17.1	17.1	15.5	24.6	18.1
TDP	uM	1.30	1.74	1.51	1.01	1.01	1.01	0.97	1.19	1.06
TSS	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	0.40	1.10	0.77	0.10	0.30	0.20	0.40	0.80	0.62
Productivity										
Alpha	ALPHA	0.02	0.05	0.03				0.01	0.04	0.02
Pmax	mgCm-3h-1	1.49	1.98	1.74				0.85	1.51	1.18
Areal Production	mgCm-2d-1	107.3	107.3	107.3				181.5	228.1	204.8
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	201.8	201.8	201.8				478.4	508.1	493.3
Respiration	uM hr-1	0.06	0.24	0.12				0.04	0.04	0.04
Plankton										
Total Phytoplankton	E6CELLS L-1	0.313	0.651		0.177	0.203		0.055	0.579	
Centric diatoms	E6CELLS L-1	0.024	0.075		0.022	0.025		0.003	0.037	
Alexandrium tamarense	CELLS L-1	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	0.001	0.001		ND	ND		ND	ND	
Total Zooplankton	ind m-3	1169.9	17223.5		12921.3	12921.3		3018.9	12901.1	

NA - Data not available due to sample loss

ND - Not detected in the sample

Table 3-3. Combined Farfield/Nearfield Survey WF982 (Feb 98) Data Summary

Region		Farfield								
		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	3.32	4.07	3.66	3.49	4.69	3.89	3.40	4.55	3.77
Salinity	PSU	30.4	32.1	31.6	30.7	31.6	31.1	29.9	31.3	30.7
Sigma _T		24.1	25.5	25.1	24.3	25.1	24.7	23.7	24.9	24.4
Beam Attenuation	m-1	0.76	1.85	1.08	0.90	1.84	1.54	0.91	1.92	1.45
DO Concentration	mg L-1	9.72	12.37	10.97	9.74	12.15	11.16	10.36	11.90	11.38
DO Saturation	PCT	91.6	111.3	99.5	91.1	109.3	102.0	96.2	110.9	105.9
Fluorescence	ug L-1	0.03	3.62	0.60	0.11	5.48	2.64	0.05	1.72	0.53
Chlorophyll a	ug L-1	0.07	1.88	0.53	0.07	3.40	1.33	0.01	0.89	0.38
Phaeopigment	ug L-1	0.09	0.27	0.17	0.10	0.99	0.31	0.07	0.68	0.30
Nutrients										
NH4	uM	0.51	1.58	0.82	0.70	2.22	1.41	0.54	6.45	2.44
NO2	uM	0.09	0.20	0.15	0.03	0.22	0.13	0.01	0.32	0.17
NO2+NO3	uM	3.44	7.50	5.30	0.46	5.66	3.83	0.36	9.09	5.04
PO4	uM	0.36	0.77	0.54	0.06	0.58	0.38	0.10	0.98	0.56
SIO4	uM	3.17	8.06	5.30	0.47	23.15	5.84	0.65	11.46	5.91
BIOSI	uM	0.80	0.80	0.80	0.70	3.70	2.67	0.10	3.10	1.19
DOC	uM	113.7	204.2	148.7	129.5	331.6	187.6	125.1	162.8	143.1
PARTP	uM	0.08	0.16	0.12	0.08	0.27	0.20	0.01	0.28	0.17
POC	uM	18.50	42.25	34.25	11.25	58.58	29.61	16.83	45.50	29.08
PON	uM	2.29	3.37	2.78	0.79	7.36	3.64	2.57	4.54	3.57
TDN	uM	14.8	15.4	15.1	17.1	23	19.9	16.5	24.3	20.8
TDP	uM	0.77	0.91	0.85	0.84	0.96	0.91	0.82	1.03	0.91
TSS	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	0.50	0.90	0.70	0.10	1.00	0.58	0.50	2.20	1.02
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM hr-1									
Plankton										
Total Phytoplankton	E6CELLS L-1	0.30	0.34		0.82	1.27		0.37	0.55	
Centric diatoms	E6CELLS L-1	0.02	0.02		0.31	0.68		0.02	0.05	
Alexandrium tamarense	CELLS L-1	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	0.0005	0.0005		0.002	0.002		ND	ND	
Total Zooplankton	ind m-3	28957.0	28957.0		14871.1	29158.9		6466.7	35230.5	

NA - Data not available due to sample loss

ND - Not detected in the sample

Table 3-3. Combined Farfield/Nearfield Survey WF982 (Feb 98) Data Summary (continued)

Region		Harbor			Offshore			Nearfield		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	3.91	4.28	4.11	3.36	4.19	3.77	3.45	4.03	3.74
Salinity	PSU	28.44	29.67	29.2	30.9	32.11	31.6	23.1	31.9	31.3
Sigma _T		22.55	23.55	23.2	24.5	25.48	25.1	18.4	25.4	24.9
Beam Attenuation	m-1	2.14	2.33	2.24	0.65	1.21	0.82	0.67	1.83	0.90
DO Concentration	mg L-1	10.45	11.94	11.16	8.43	12.70	10.90	9.41	12.36	10.75
DO Saturation	PCT	97.19	110.71	103.7	78.4	118.61	102.1	88.2	114.5	100.4
Fluorescence	ug L-1	0.71	1.12	0.94	0.00	0.93	0.31	0.00	0.83	0.31
Chlorophyll a	ug L-1	0.05	0.86	0.39	0.07	0.52	0.33	0.01	18.36	0.73
Phaeopigment	ug L-1	0.05	1.02	0.47	0.05	2.16	0.60	0.04	0.59	0.16
Nutrients										
NH4	uM	0.24	7.33	5.26	0.32	1.74	0.78	0.24	3.76	1.03
NO2	uM	0.03	0.38	0.29	0.04	0.16	0.12	0.03	0.21	0.12
NO2+NO3	uM	0.20	9.69	7.95	0.99	6.90	4.66	0.36	6.34	4.19
PO4	uM	0.09	0.77	0.60	0.15	0.80	0.55	0.09	0.69	0.52
SIO4	uM	0.35	14.29	11.03	0.67	8.46	4.37	1.31	13.51	5.16
BIOSI	uM	0.40	3.20	2.14	0.30	0.30	0.30	0.10	2.50	0.69
DOC	uM	136	161.7	149.2	109.9	148.3	125.3	103.5	152.3	126.3
PARTP	uM	0.25	0.38	0.32	0.09	0.11	0.10	0.06	0.20	0.09
POC	uM	28.17	36.92	32.66	11.75	13.00	12.22	4.80	23.00	12.98
PON	uM	3.46	5.29	4.49	2.20	2.92	2.52	1.49	3.65	2.29
TDN	uM	26.6	31.8	28.1	14.8	16.3	15.6	12.6	20.9	15.6
TDP	uM	0.62	1.20	1.04	0.85	0.90	0.87	0.77	0.92	0.84
TSS	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	0.70	2.20	1.18	0.20	0.70	0.45	0.30	0.60	0.47
Productivity										
Alpha	ALPHA	0.023	0.047	0.031				0.008	0.062	0.027
Pmax	mgCm-3h-1	1.55	2.03	1.83				0.90	1.55	1.21
Areal Production	mgCm-2d-1	97.5	97.5	97.5				160.2	209.9	185.1
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	147.9	147.9	147.9				NA	NA	NA
Respiration	uM hr-1	0.074	0.095	0.084	0.014	0.095	0.048	0.026	0.049	0.036
Plankton										
Total Phytoplankton	E6CELLS L-1	0.41	0.80		0.32	0.37		0.21	0.46	
Centric diatoms	E6CELLS L-1	0.03	0.05		0.02	0.02		0.01	0.04	
Alexandrium tamarense	CELLS L-1	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	ND	ND		0.0005	0.0006		0.002	0.003	
Total Zooplankton	ind m-3	4792.3	8142.2		57186.07	57186.07		9229.5	33014.6	

NA - Data not available due to sample loss

ND - Not detected in the sample

Table 3-4. Nearfield Survey WF983 (Mar 98) Data Summary

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	2.83	3.80	3.11
Salinity	PSU	29.3	31.7	30.5
Sigma _T		23.3	25.2	24.3
Beam Attenuation	m-1	0.82	2.51	1.28
DO Concentration	mg L-1	9.71	12.04	11.21
DO Saturation	PCT	90.1	109.6	102.5
Fluorescence	ug L-1	0.10	3.86	1.28
Chlorophyll a	ug L-1	0.02	1.89	0.52
Phaeopigment	ug L-1	0.08	1.14	0.34
Nutrients				
NH4	uM	0.32	6.64	1.50
NO2	uM	0.01	0.34	0.12
NO2+NO3	uM	0.41	11.61	3.79
PO4	uM	0.09	0.80	0.49
SIO4	uM	1.41	10.16	6.20
BIOSI	uM	0.90	35.80	3.49
DOC	uM	115.2	550.7	205.0
PARTP	uM	0.08	0.33	0.15
POC	uM	7.78	27.67	16.28
PON	uM	1.29	3.94	2.47
TDN	uM	15.9	34.5	22.9
TDP	uM	0.71	1.02	0.82
TSS	ug L-1	NA	NA	NA
Urea	uM	0.50	3.20	1.70
Productivity				
Alpha	ALPHA	0.005	0.098	0.040
Pmax	mgCm-3h-1	0.43	3.12	0.98
Areal Production	mgCm-2d-1	206.3	284.9	245.6
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	563.9	563.9	563.9
Respiration	uM hr-1	0.028	0.031	0.030
Plankton				
Total Phytoplankton	E6CELLS L-1	0.41	0.61	
Centric diatoms	E6CELLS L-1	0.010	0.028	
Alexandrium tamarense	CELLS L-1	ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	0.001	0.002	
Total Zooplankton	ind m-3	28709.1	30353.1	

NA - Data not available due to sample loss
ND - Not detected in the sample

Table 3-5. Combined Farfield/Nearfield Survey WF984 (Apr 98) Data Summary

Region		Farfield								
		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	3.06	5.12	4.12	3.57	5.71	4.75	3.64	5.97	5.01
Salinity	PSU	30.5	31.7	31.0	23.8	31.1	30.3	29.9	30.8	30.3
Sigma _T		24.1	25.2	24.6	18.8	24.7	24.0	23.5	24.5	23.9
Beam Attenuation	m-1	0.70	1.21	0.84	0.84	3.43	1.32	0.85	1.84	1.43
DO Concentration	mg L-1	9.39	11.10	10.57	10.38	11.86	11.07	9.21	11.52	10.27
DO Saturation	PCT	88.0	106.8	99.5	96.4	113.4	105.3	89.4	108.8	98.3
Fluorescence	ug L-1	0.12	1.88	0.87	0.21	4.87	2.24	0.49	4.39	1.76
Chlorophyll a	ug L-1	0.50	2.54	1.55	0.44	5.73	2.62	0.63	4.15	2.15
Phaeopigment	ug L-1	0.55	1.51	1.10	0.32	3.71	1.91	0.46	2.65	1.57
Nutrients										
NH4	uM	0.61	3.98	1.15	0.32	2.36	0.79	0.83	6.32	2.68
NO2	uM	0.11	0.18	0.14	0.05	0.13	0.10	0.13	0.28	0.19
NO2+NO3	uM	2.49	6.07	4.42	0.60	5.55	2.96	3.92	5.96	5.10
PO4	uM	0.28	0.70	0.47	0.36	0.98	0.64	0.37	0.69	0.54
SIO4	uM	3.09	10.69	5.60	1.83	5.73	4.00	5.22	8.77	6.50
BIOSI	uM	0.10	0.90	0.57	0.70	3.20	2.13	1.20	2.60	1.69
DOC	uM	144.2	172.5	163.0	133.6	246.1	197.7	149.8	204.5	168.4
PARTP	uM	0.08	0.18	0.13	0.10	0.25	0.16	0.12	0.29	0.20
POC	uM	9.50	31.67	19.42	13.08	29.67	20.57	11.42	26.67	19.18
PON	uM	1.64	3.74	2.79	2.52	4.86	3.56	2.04	4.48	3.29
TDN	uM	16.4	26.2	21.0	16.2	38.9	24.2	20.3	28.0	23.9
TDP	uM	0.73	0.82	0.78	0.50	0.94	0.67	0.79	0.99	0.90
TSS	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	0.80	1.30	1.05	0.50	1.20	0.90	0.90	2.70	1.70
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM hr-1									
Plankton										
Total Phytoplankton	E6CELLS L-1	0.53	0.72		0.56	2.51		0.45	0.97	
Centric diatoms	E6CELLS L-1	0.07	0.09		0.10	1.57		0.08	0.17	
Alexandrium tamarense	CELLS L-1	2.5	5.0		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	0.002	0.002		0.002	0.017		0.001	0.005	
Total Zooplankton	ind m-3	27109.4	27109.4		13261.6	28397.5		16716.8	70954.9	

NA - Data not available due to sample loss

ND - Not detected in the sample

Table 3-5. Combined Farfield/Nearfield Survey WF984 (Apr 98) Data Summary (continued)

Region		Harbor			Offshore			Nearfield		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	5.36	6.61	5.93	2.90	5.16	3.95	3.12	5.38	4.10
Salinity	PSU	28.5	30.1	29.5	30.3	31.6	30.8	29.0	31.3	30.6
Sigma _T		22.4	23.7	23.2	24.0	25.1	24.5	23.0	24.9	24.3
Beam Attenuation	m-1	1.42	2.45	2.09	1.02	1.63	1.10	1.06	2.22	1.24
DO Concentration	mg L-1	9.46	10.50	9.97	9.44	10.85	10.41	9.28	11.28	10.44
DO Saturation	PCT	92.4	101.4	97.0	87.8	103.0	97.4	85.8	106.2	97.9
Fluorescence	ug L-1	0.85	1.40	1.05	0.09	1.33	0.59	0.02	2.49	0.89
Chlorophyll a	ug L-1	0.11	5.58	2.08	0.45	1.17	0.85	0.19	3.47	0.89
Phaeopigment	ug L-1	0.23	7.87	2.11	0.47	0.80	0.62	0.20	2.66	0.78
Nutrients										
NH4	uM	4.42	8.35	6.68	0.50	1.49	0.92	0.37	5.85	1.18
NO2	uM	0.24	0.33	0.28	0.11	0.20	0.14	0.07	0.22	0.12
NO2+NO3	uM	5.81	7.50	6.60	3.98	5.13	4.40	2.34	7.70	4.43
PO4	uM	0.60	0.87	0.73	0.47	0.69	0.56	0.33	0.88	0.56
SIO4	uM	8.07	12.24	9.51	4.37	10.19	5.67	3.20	11.60	6.25
BIOSI	uM	2.00	4.10	2.90	0.60	1.20	0.83	0.20	2.00	0.73
DOC	uM	141.7	240.5	192.0	119.7	206.6	173.4	112.8	402.7	197.8
PARTP	uM	0.19	0.34	0.28	0.10	0.17	0.12	0.05	0.22	0.12
POC	uM	21.17	37.00	27.07	7.11	16.50	11.18	5.32	21.42	13.19
PON	uM	3.39	5.63	4.10	1.44	3.12	2.15	1.06	3.64	2.30
TDN	uM	21.5	34.1	28.6	15.6	20.9	17.5	14.9	49.3	21.6
TDP	uM	0.82	1.25	1.02	0.68	0.76	0.72	0.61	1.05	0.79
TSS	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	1.10	4.00	1.80	1.30	1.60	1.45	1.10	1.80	1.43
Productivity										
Alpha	ALPHA	0.015	0.022	0.018				0.004	0.018	0.010
Pmax	mgCm-3h-1	2.34	2.94	2.64				0.32	1.40	0.85
Areal Production	mgCm-2d-1	126.4	126.4	126.4				126.4	164.9	145.7
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	99.0	99.0	99.0				134.9	134.9	134.9
Respiration	uM hr-1	0.069	0.087	0.078	0.024	0.088	0.056	0.013	0.11	0.057
Plankton										
Total Phytoplankton	E6CELLS L-1	0.62	1.06		0.23	0.30		0.28	0.48	
Centric diatoms	E6CELLS L-1	0.12	0.21		0.02	0.04		0.02	0.02	
Alexandrium tamarense	CELLS L-1	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	0.001	0.002		0.002	0.004		0.0003	0.002	
Total Zooplankton	ind m-3	1533.8	34282.2		34022.1	34022.1		42130.5	56036.5	

NA - Data not available due to sample loss

ND - Not detected in the sample

Table 3-6.. Nearfield Survey WF985 (Apr 98) Data Summary

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	4.25	9.97	7.00
Salinity	PSU	29.1	31.1	29.9
Sigma _T		22.4	24.7	23.4
Beam Attenuation	m-1	0.89	1.83	1.23
DO Concentration	mg L-1	9.38	12.71	11.08
DO Saturation	PCT	89.7	126.0	111.0
Fluorescence	ug L-1	0.07	6.04	1.79
Chlorophyll a	ug L-1	0.14	3.19	1.12
Phaeopigment	ug L-1	0.01	2.81	0.33
Nutrients				
NH4	uM	0.14	4.55	1.02
NO2	uM	0.01	0.16	0.05
NO2+NO3	uM	0.05	3.57	0.72
PO4	uM	0.18	0.64	0.32
SIO4	uM	1.83	24.33	6.52
BIOSI	uM	0.10	2.20	1.08
DOC	uM	137.2	245.2	181.8
PARTP	uM	0.07	0.35	0.20
POC	uM	15.30	35.60	23.87
PON	uM	2.45	5.76	3.53
TDN	uM	12.4	26.5	16.9
TDP	uM	0.42	0.87	0.56
TSS	ug L-1	1.72	8.73	4.45
Urea	uM	1.20	3.10	1.75
Productivity				
Alpha	ALPHA	0.011	0.064	0.029
Pmax	mgCm-3h-1	1.20	3.07	2.29
Areal Production	mgCm-2d-1	302.7	348.0	325.4
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	282.2	282.2	282.2
Respiration	uM hr-1	0.05	0.18	0.11
Plankton				
Total Phytoplankton	E6CELLS L-1	0.59	2.22	
Centric diatoms	E6CELLS L-1	0.15	0.35	
Alexandrium tamarense	CELLS L-1	ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	0.0042	0.0042	
Total Zooplankton	ind m-3	9968.9	31538.5	

ND - Not detected in the sample

Table 3-7. Nearfield Survey WN986 (May 98) Data Summary

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	4.84	12.53	8.43
Salinity	PSU	27.1	31.2	29.6
Sigma _T		20.3	24.7	22.9
Beam Attenuation	m-1	0.61	2.45	0.88
DO Concentration	mg L-1	9.38	10.78	9.87
DO Saturation	PCT	89.9	116.3	102.0
Fluorescence	ug L-1	0.01	8.74	1.68
Chlorophyll a	ug L-1	0.15	3.33	1.14
Phaeopigment	ug L-1	0.09	1.59	0.78
Nutrients				
NH4	uM	0.14	7.67	1.12
NO2	uM	0.01	0.68	0.074
NO2+NO3	uM	0.02	3.66	0.86
PO4	uM	0.09	0.65	0.31
SIO4	uM	2.91	7.32	4.73
BIOSI	uM	0.40	3.90	1.61
DOC	uM	123.8	455.9	224.80
PARTP	uM	0.08	0.55	0.26
POC	uM	8.10	31.60	15.57
PON	uM	1.59	5.14	2.69
TDN	uM	9.6	19.3	13.9
TDP	uM	0.37	1.07	0.56
TSS	ug L-1	1.17	8.38	4.62
Urea	uM	0.30	1.00	0.60
Productivity				
Alpha	ALPHA	0.002	0.026	0.017
Pmax	mgCm-3h-1	0.12	8.03	2.40
Areal Production	mgCm-2d-1	340.3	403.8	372.1
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	256.6	396.0	326.3
Respiration	uM hr-1	0.009	0.144	0.076
Plankton				
Total Phytoplankton	E6CELLS L-1	0.58	1.23	
Centric diatoms	E6CELLS L-1	0.11	0.42	
Alexandrium tamarense	CELLS L-1	ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND	
Pseudo-nitzschia sp	CELLS L-1	ND	ND	
Total Zooplankton	ind m-3	51954.6	72650.7	

ND - Not detected in the sample

Table 3-8. Combined Farfield/Nearfield Survey WF987 (Jun 98) Data Summary

		Farfield								
Region		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	4.66	14.02	7.92	4.77	15.65	7.41	5.69	14.40	10.27
Salinity	PSU	27.3	31.9	30.8	29.0	32.2	30.5	26.2	31.5	29.7
Sigma _T		20.6	25.2	24.0	21.2	25.4	23.8	19.3	24.8	22.7
Beam Attenuation	m-1	0.63	1.61	0.99	0.92	1.40	1.18	0.87	2.23	1.51
DO Concentration	mg L-1	10.84	12.53	11.64	8.99	11.10	10.05	10.11	13.66	11.41
DO Saturation	PCT	106.4	133.0	119.8	94.9	120.0	105.0	87.5	138.3	116.0
Fluorescence	ug L-1	1.51	13.08	6.48	1.64	3.46	2.64	1.15	13.12	5.79
Chlorophyll a	ug L-1	0.16	8.41	1.90	0.46	5.19	2.04	1.49	11.46	5.75
Phaeopigment	ug L-1	0.19	1.30	0.49	0.11	1.20	0.38	0.01	1.73	0.80
Nutrients										
NH4	uM	0.12	1.39	0.79	0.38	2.54	1.35	0.17	3.45	1.35
NO2	uM	0.02	0.25	0.13	0.09	0.32	0.24	0.01	0.26	0.12
NO2+NO3	uM	0.01	8.93	3.19	0.21	5.52	3.69	0.09	4.14	1.70
PO4	uM	0.06	0.88	0.45	0.12	0.90	0.63	0.07	0.89	0.44
SIO4	uM	0.05	7.71	3.47	0.30	10.85	6.65	0.37	6.21	2.68
BIOSI	uM	0.60	1.80	1.20	1.20	2.70	2.18	2.50	5.20	3.74
DOC	uM	132.3	485.6	253.9	131.1	1014.2	380.0	137.9	1098.6	438.8
PARTP	uM	0.06	0.13	0.09	0.10	0.24	0.16	0.27	0.63	0.47
POC	uM	12.00	24.40	19.57	11.70	28.80	21.43	23.60	75.60	42.76
PON	uM	1.82	2.79	2.45	1.71	3.75	2.70	0.76	10.79	5.80
TDN	uM	11.9	21.2	17.6	13.6	28.7	17.1	9.7	57.9	23.2
TDP	uM	0.48	1.12	0.77	0.28	1.02	0.77	0.38	1.03	0.68
TSS	ug L-1	2.24	2.90	2.67	2.97	10.28	6.51	2.88	6.17	4.23
Urea	uM	0.40	1.00	0.70	0.50	0.80	0.65	0.50	0.70	0.57
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM hr-1									
Plankton										
Total Phytoplankton	E6CELLS L-1	0.16	0.20		0.46	1.50		0.88	4.93	
Centric diatoms	E6CELLS L-1	0.044	0.066		0.11	1.00		0.61	3.73	
Alexandrium tamarense	CELLS L-1	1.23	1.23		2.5	3.1		1.4	2.5	
Phaeocystis pouchettii	CELLS L-1	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	ND	ND		ND	ND		0.0016	0.0048	
Total Zooplankton	ind m-3	53951.4	53951.4		15768.8	15977.6		14715.9	46392.5	

NA - Data not available due to sample loss

ND - Not detected in the sample

Table 3-8. Combined Farfield/Nearfield Survey WF987 (Jun 98) Data Summary (continued)

Region		Harbor			Offshore			Nearfield		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	9.76	16.20	13.25	4.33	13.23	6.59	5.32	16.92	10.46
Salinity	PSU	22.7	30.1	27.7	27.0	31.7	31.0	24.9	31.5	29.7
Sigma _T		16.3	23.2	20.7	20.2	25.1	24.3	17.9	24.8	22.7
Beam Attenuation	m-1	1.72	3.12	2.25	0.64	2.16	1.04	0.59	1.57	0.83
DO Concentration	mg/L	9.97	11.33	10.82	10.56	13.20	11.87	10.26	12.17	11.21
DO Saturation	PCT	116.6	131.6	122.2	101.0	137.4	117.6	103.6	138.7	121.1
Fluorescence	ug L-1	4.02	11.25	6.33	1.63	26.63	8.07	1.45	7.57	3.57
Chlorophyll a	ug L-1	4.57	11.12	6.79	0.29	9.33	3.97	0.26	5.29	1.39
Phaeopigment	ug L-1	0.57	1.69	1.18	0.01	0.34	0.20	0.03	1.12	0.42
Nutrients										
NH4	uM	1.53	9.34	4.86	0.11	2.16	1.02	0.18	4.26	0.91
NO2	uM	0.11	0.49	0.23	0.01	0.31	0.18	0.01	0.31	0.08
NO2+NO3	uM	1.08	9.17	3.21	0.02	10.06	4.21	0.01	5.53	0.83
PO4	uM	0.06	0.66	0.43	0.13	0.91	0.61	0.03	0.77	0.27
SIO4	uM	2.29	15.79	4.91	0.24	8.60	4.85	0.13	11.42	3.08
BIOSI	uM	3.30	6.80	5.29	1.80	5.50	3.63	0.32	4.80	2.11
DOC	uM	181.3	490.0	261.7	139.2	245.4	174.9	122.4	1954.4	367.5
PARTP	uM	0.49	0.85	0.64	0.08	0.51	0.36	0.07	0.48	0.20
POC	uM	41.00	70.10	51.80	13.10	50.00	35.83	7.30	51.20	23.19
PON	uM	6.42	11.50	8.38	1.60	6.66	4.82	1.69	7.11	3.66
TDN	uM	15.8	35.2	25.6	16.8	16.8	16.8	7.8	34.3	14.7
TDP	uM	0.44	1.13	0.88	0.52	0.52	0.52	0.31	1.00	0.57
TSS	ug L-1	3.25	16.00	7.52	3.72	5.93	5.11	0.43	9.58	4.06
Urea	uM	0.50	1.90	0.98	0.50	0.60	0.55	0.20	0.60	0.37
Productivity										
Alpha	ALPHA	0.06	0.13	0.10				0.01	0.07	0.02
Pmax	mgCm-3h-1	11.50	48.03	23.06				0.50	6.26	1.73
Areal Production	mgCm-2d-1	1103.9	1103.9	1103.9				194.3	314.2	254.3
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	157.7	157.7	157.7				223.1	289.3	256.2
Respiration	uM/hr	NA	NA	NA				NA	NA	NA
Plankton										
Total Phytoplankton	E6CELLS L-1	1.64	3.74		1.92	2.84		0.15	2.03	
Centric diatoms	E6CELLS L-1	0.91	2.46		1.39	2.35		0.038	1.58	
Alexandrium tamarense	CELLS L-1	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchettii	CELLS L-1	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	0.0098	0.0098		ND	ND		ND	ND	
Total Zooplankton	ind m-3	37583.0	289811.3		14562.3	14562.3		23258.8	69756.4	

NA - Data not available due to sample loss

ND - Not detected in the sample

Table 3-8. Nearfield Survey WF988 (Jul 98) Data Summary

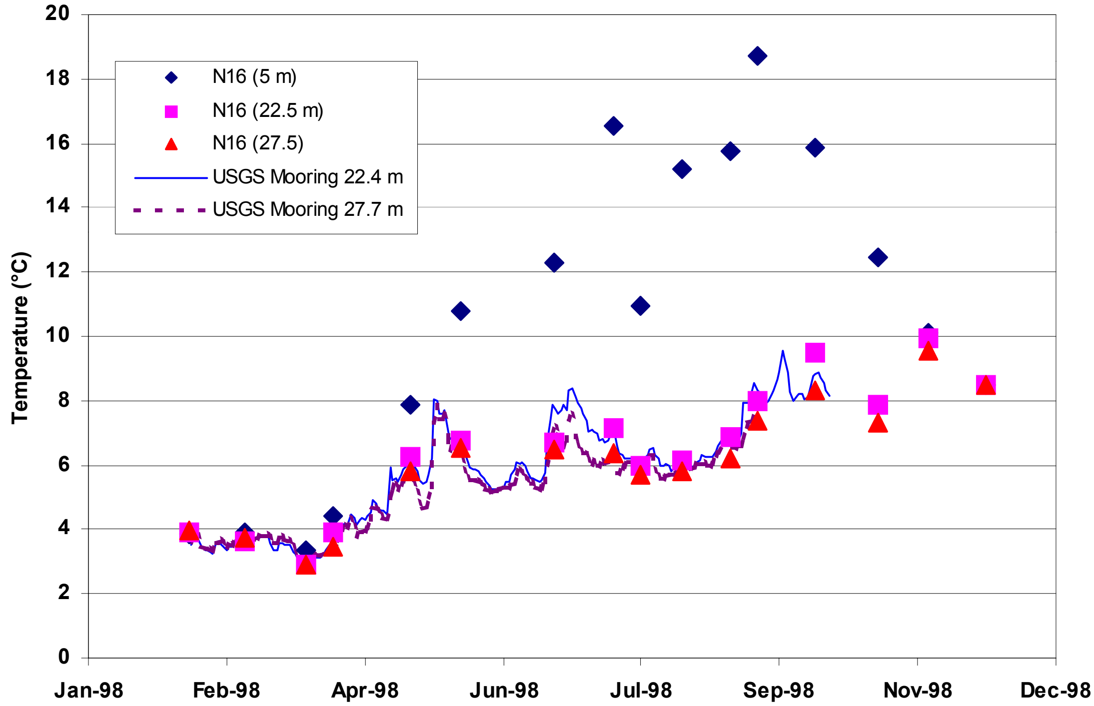
		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	5.08	19.02	10.83
Salinity	PSU	28.1	31.6	30.3
Sigma _T		19.9	25.0	23.1
Beam Attenuation	m-1	0.50	2.19	0.99
DO Concentration	mg L-1	8.96	11.78	10.39
DO Saturation	PCT	93.4	138.1	113.1
Fluorescence	ug L-1	0.03	7.42	1.75
Chlorophyll a	ug L-1	0.04	8.04	1.50
Phaeopigment	ug L-1	0.03	2.33	0.40
Nutrients				
NH4	uM	0.02	3.95	1.01
NO2	uM	0.01	4.52	0.21
NO2+NO3	uM	0.01	10.97	2.89
PO4	uM	0.01	0.99	0.52
SIO4	uM	0.06	10.87	4.24
BIOSI	uM	0.90	3.80	1.52
DOC	uM	140.8	305.0	210.5
PARTP	uM	0.10	0.50	0.29
POC	uM	7.90	45.70	23.44
PON	uM	1.06	6.52	3.22
TDN	uM	10.7	30.0	19.3
TDP	uM	0.35	1.22	0.76
TSS	ug L-1	1.00	8.47	3.97
Urea	uM	0.20	0.60	0.47
Productivity				
Alpha	ALPHA	0.0004	0.024	0.0079
Pmax	mgCm-3h-1	0.12	2.19	0.72
Areal Production	mgCm-2d-1	140.2	197.0	168.6
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	120.7	370.8	245.8
Respiration	uM hr-1	0.07	0.26	0.19
Plankton				
Total Phytoplankton	E6CELLS L-1	1.14	3.31	
Centric diatoms	E6CELLS L-1	0.08	0.94	
Alexandrium tamarense	CELLS L-1	2.3	2.5	
Phaeocystis pouchettii	CELLS L-1	ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	0.0015	0.0015	
Total Zooplankton	ind m-3	28686.9	32216.2	

ND - Not detected in the sample

Table 3-9. Nearfield Survey WN989 (Jul 98) Data Summary

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	5.12	18.03	9.75
Salinity	PSU	29.9	31.6	30.9
Sigma _T		21.5	25.0	23.7
Beam Attenuation	m-1	0.52	3.06	1.08
DO Concentration	mg L-1	6.83	14.58	11.05
DO Saturation	PCT	68.2	140.0	110.2
Fluorescence	ug L-1	0.02	18.74	3.11
Chlorophyll a	ug L-1	0.18	9.60	2.53
Phaeopigment	ug L-1	0.01	0.85	0.30
Nutrients				
NH4	uM	0.14	2.77	0.74
NO2	uM	0.01	0.28	0.14
NO2+NO3	uM	0.04	8.75	3.04
PO4	uM	0.01	0.92	0.52
SIO4	uM	0.16	8.95	4.02
BIOSI	uM	0.50	4.40	1.49
DOC	uM	148.2	581.7	224.9
PARTP	uM	0.02	0.51	0.22
POC	uM	7.80	60.70	27.74
PON	uM	1.29	8.14	3.91
TDN	uM	10.5	37.2	18.6
TDP	uM	0.34	1.06	0.79
TSS	ug L-1	0.80	10.67	3.20
Urea	uM	0.10	1.20	0.70
Productivity				
Alpha	ALPHA	0.004	0.038	0.015
Pmax	mgCm-3h-1	0.29	1.31	0.61
Areal Production	mgCm-2d-1	114.1	176.1	145.1
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	65.5	307.9	186.7
Respiration	uM hr-1	0.07	0.32	0.16
Plankton				
Total Phytoplankton	E6CELLS L-1	1.38	2.46	
Centric diatoms	E6CELLS L-1	0.03	0.71	
Alexandrium tamarense	CELLS L-1	1.1	1.1	
Phaeocystis pouchettii	CELLS L-1	ND	ND	
Psuedo-nitzschia pungens	E6CELLS L-1	0.001	0.006	
Total Zooplankton	ind m-3	26820.8	44344.5	

ND - Not detected in the sample



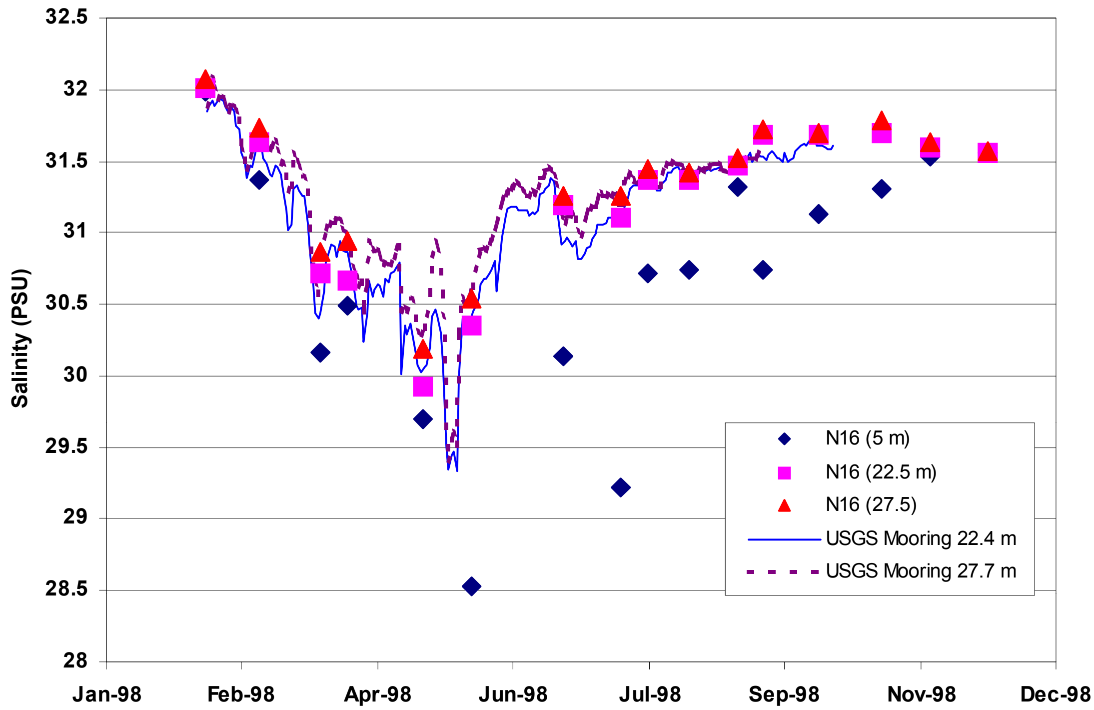


Figure 3-1. USGS Temperature and Salinity Mooring Data from 20 Meters Below Surface and 1 Meter Above Bottom

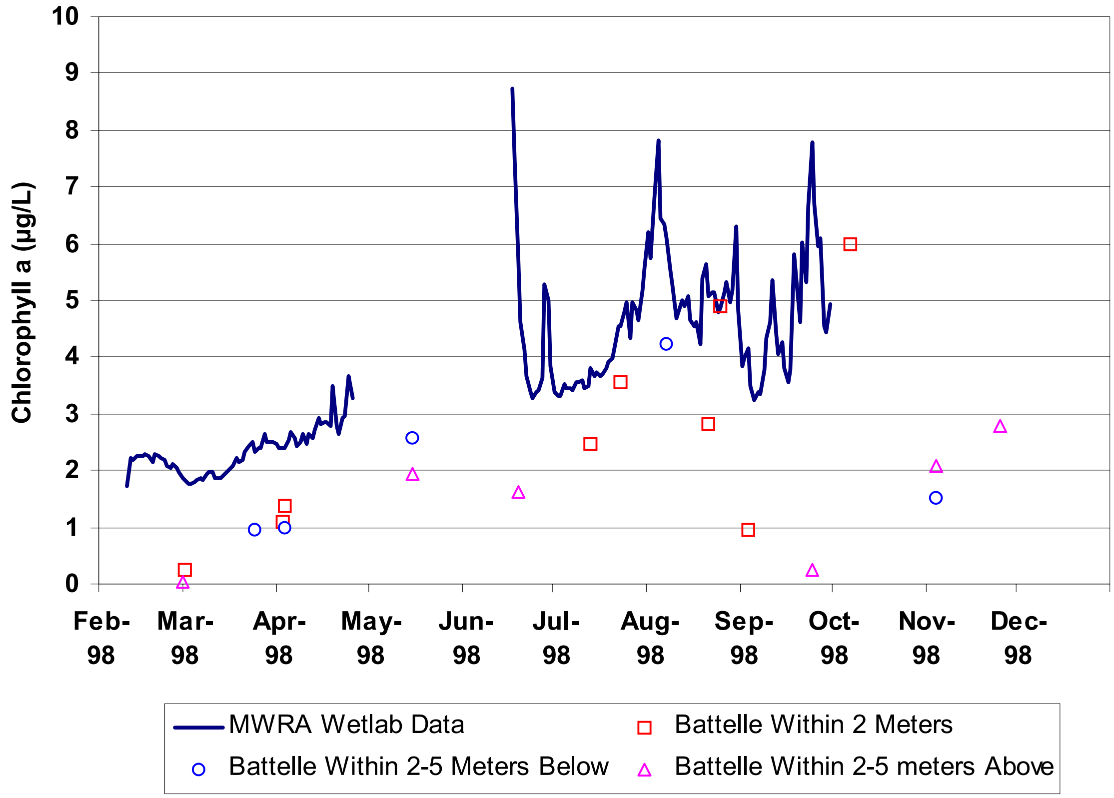


Figure 3-2. MWRA and Battelle Wetlab Chlorophyll a Data

4.0 RESULTS OF WATER COLUMN MEASUREMENTS

Data presented in this section are organized by type of data and survey. Physical data, including temperature, salinity, density, and beam attenuation are presented in Section 4.1. Nutrients, chlorophyll a, and dissolved oxygen are discussed in Section 4.2. Finally a summary of the major results of water column measurements (excepting biological measurements) is provided in Section 4.3.

Four of the nine surveys conducted during the semi-annual period were combined farfield/nearfield surveys. The first three combined surveys in February (WF981 and WF982) and April (WF984) were conducted prior to stratification of the water column. The last combined survey (WF987) was conducted in June following record rainfall in the Boston area (8.5 inches in seven days). Very strong density gradients were observed between surface and bottom waters throughout the nearfield during this survey (Figure 4-1). Data collected during the farfield surveys were evaluated for trends in regional water masses throughout the Boston Harbor, Massachusetts Bay, and Cape Cod Bay. The variation of regional surface water properties is presented using contour plots of surface water parameters, derived from the A (surface) water sample. Classifying data by regions allows comparison of the horizontal distribution of water mass properties over the farfield area.

The vertical distribution of water column parameters is presented in the following sections along three farfield transects (Boston-Nearfield, Cohassett, and Marshfield) in the survey area, and one transect across the Nearfield (Figure 1-3). Examining data trends along transects provides a three-dimensional perspective of water column conditions during each survey. Nearfield surveys were conducted more frequently than farfield surveys, allowing better temporal resolution of the changes in water column parameters and onset stratification. In addition to the nearfield vertical transect (Figure 1-3), vertical variability in nearfield data is examined and presented by comparing surface and bottom water concentrations (A and E depths) and by plotting individual parameters with depth in the water column. A complete set the surface contour maps, vertical transect plots, and parameter scatter plots is provided in Appendices B, C, and D, respectively.

4.1 Physical Characteristics

4.1.1 Temperature\Salinity\Density

The timing of the annual setup of vertical stratification in the water column is an important determinant of water quality, primarily because of the trend towards continuously decreasing dissolved oxygen in bottom water in the summer and early fall. The pycnocline, defined as a shallow water depth interval over which density increases rapidly, is caused by a combination of freshwater input during spring runoff, and warming of surface water in the summer. Above the pycnocline the surface water is well mixed, and below the pycnocline density increases more gradually. As mentioned above, the surface and bottom water density data collected during the combined surveys indicated that seasonal stratification had been established by the time of the June survey throughout the region. Nearfield surveys activities are conducted more frequently and provide a more detailed evaluation on the onset of stratification. For the purposes of this report, the water column is stratified when the difference between surface and bottom water density is greater than 1.0 sigma-t units. Using this definition, the water column was stratified by mid-May (Figure 4-1). The density profiles indicate that the pycnocline was developing across the nearfield region by late April (WN985) (Figure 4-2).

4.1.1.1 Horizontal Distribution

In early February (WF981), surface water temperatures were fairly uniform (3.7°C ± 1°C) across the entire farfield/nearfield area. The surface water temperatures ranged from 2.65°C at station F31 in the harbor to 4.81°C at boundary station F29. In general, there was an inshore to offshore increase in temperatures (Figure 4-3). Surface water salinity was also fairly uniform throughout Massachusetts and Cape Cod Bays. Salinity ranged between 30.4 and 32.3 PSU (Figure 4-4). Lower salinity values were observed within the harbor and at the stations located off of Gloucester. Higher salinity values were found from the nearfield area southward to Cape Cod Bay. The highest salinity was concomitant with the highest surface temperature at the boundary station F29.

Surface water temperatures in late February (WF982) continued to be uniform (4°C ± 0.6°C) throughout the farfield/nearfield area ranging from 3.36°C at farfield station F22 to 4.69°C at Cape Cod Bay station F01. The distribution of minimum and maximum surface temperatures followed the general trend of increasing temperatures to the south. The pattern observed in the surface salinity data indicated a strong (~3 PSU) gradient between inshore and offshore stations. Due to heavy rainfall in late February, surface water salinity in the harbor was relatively low (28.43 – 29.27 PSU), as were the salinity values at the coastal stations (<30.5 PSU).

By early April (WF984), surface water temperature had increased (5.4°C ± 1.2°C) and there was a decreasing temperature gradient from inshore to offshore (Figure 4-5). The highest surface temperature was observed at harbor station F30 and the lowest at offshore station F17. The surface salinity values increased from inshore to offshore (Figure 4-6) with the minimum at harbor station F23 (28.47 PSU) and the maximum at boundary station F12 (30.95 PSU). The changes that were observed in surface temperatures and salinity from February (WF981 and WF982) to April (WF984) are indicative of the onset of seasonal stratification. By examining the temperature-salinity (T-S) plots, there is a clear change in the relationship between these two parameters between WF981 and WF984 (Figure 4-7). In early February, the trend within each of the regions was that increasing temperatures were concurrent with increasing salinity. The surface waters were generally cooler and less saline than bottom waters and thus the density gradient was not significant. By early April, this trend had reversed and higher temperatures were concomitant with lower salinity. In general, during this survey, surface waters were warmer and less saline. Bottom waters were cooler and more saline. The differences between the surface and bottom waters in April, however, had not yet led to the development of a stratified water column.

The next farfield survey was conducted two months later, but during that time period two nearfield surveys were conducted. These surveys provide an indication of the changing physical characteristics during this period when the seasonal stratification of the water column was developing. Nearfield survey WN985 (April 30 – May 1) documented an increase in surface water temperatures of 3-4°C from the previous survey. This increase was coincident with a small decrease in salinity within the nearfield area to 29.08 – 29.75 PSU. By mid-May (WN986), surface temperatures had increased to 10.8°C (N04) – 12.5°C (N11) and surface salinity continued to decrease ranging from 27.1 PSU at station N11 to 28.9 PSU at N08. This represents a decrease of about 1.5 PSU in two weeks in comparison to the values documented during WN985. The increase in surface temperature and decrease in surface salinity are the typical seasonal patterns that lead to the stratification of the water column (see Figure 4-1).

During the June farfield/nearfield survey (WF987), surface water temperature across the farfield region varied almost 9°C (Figure 4-8). The highest temperatures were observed in the harbor and nearfield areas (16.92°C at N20) and the lowest temperatures in Cape Cod Bay (7.98°C at F03). Surface water salinity varied over a very large range with the lowest salinity found in the harbor (22.7

PSU at F30) and the highest salinity being found in Massachusetts and Cape Cod Bays (30.6 PSU at F05). Low salinity surface waters were observed along the coast from Boston to Gloucester and into the northern and eastern portion of the nearfield (Figure 4-9). The low salinity values resulted from record rainfall (8.5 inches between June 12th and June 18th) which caused increased runoff in early June (Figure 4-10). The effect of the rainfall and decreased salinity was very evident when comparing surface density in the nearfield during this survey (WF987) with previous and subsequent surveys (see Figure 4-1).

4.1.1.2 Vertical Distribution

Farfield. The water column was well mixed throughout the region during the winter and early spring of 1998. As suggested previously, the density gradient ($\Delta\sigma_t$), representing the difference between the bottom and surface water σ_t, can be used as a relative indicator of a mixed or vertically stratified water column. During the first three farfield surveys (February – April), there was a decrease in surface and bottom water density throughout the farfield area (Figure 4-11), which coincided with a decrease in surface and bottom water salinity (Figure 4-12). The density gradient during all three surveys was <1.0 and ranged from $\Delta\sigma_t$ of 0.1in early February (harbor, coastal, and offshore) to $\Delta\sigma_t$ of ~0.7 in early April (offshore and boundary). There was little change in $\Delta\sigma_t$ at the boundary stations (~0.7) or the Cape Cod Bay stations (~0.2) over this two month time period. By June, however, a strong density gradient ($\Delta\sigma_t$ of 2.0-3.5) was observed at all the regions indicating that the water column was vertically stratified throughout the farfield area.

The seasonal establishment of stratified conditions was also clearly illustrated in the vertical contour plots of temperature, salinity, and sigma-T for the Boston-Nearfield, Cohassett, and Marshfield transects (Appendix C). In February (WF982), there was little variation in these parameters over the water column, though as shown in the transect plots for σ_t, there was an increase in density from inshore to offshore (Figure 4-13). In early April (WF984), the physical characteristics of the water column indicated the onset of seasonal stratification with an increase in the density gradient between the surface and bottom waters. By June (WF987), a strong pycnocline had developed throughout the region (Figure 4-14). Low salinity surface waters resulting from the June rain event and increased runoff drove the density gradient between surface and bottom waters. The harbor and coastal fresh water signature is clearly evident along the Boston-Nearfield transect (Figure 4-15). A complete set of farfield transect plots of physical water properties is provided in Appendix C.

Nearfield. The onset of stratification can be observed more clearly from the data collected in the nearfield area. The nearfield surveys are conducted on a more frequent basis and thus provide a more detailed picture of the physical characteristics of the water column. In Figure 4-16, it is evident that the water column had begun to stratify by early May (WN985) and that by mid-May there was a strong density gradient ($\Delta\sigma_t$ of 2-3) between the surface and bottom waters in the nearfield area. During the June survey (WF987), a very strong density gradient ($\Delta\sigma_t$ >5) was observed at the Inner Nearfield and Broad Sound stations (see Figure 4-1). The nearfield water column remained stratified through the rest of this reporting period. The physical characteristics that led to the establishment of stratified conditions are detailed below.

The nearfield water column was well mixed with respect to temperature (Figure 4-17) during the first four surveys of 1998. The temperature gradient between surface and bottom waters in the nearfield was negligible until April and even then only a 1-2 °C gradient was observed. Between April (WF984) and early May (WN985), surface water temperature increased to 9 °C while bottom water temperature stayed around 5 °C across the nearfield. The gradient between surface and bottom waters continued to increase with the establishment of seasonal stratification. The vertical transects presented in Figure 4-18 illustrate the development of the thermocline over the nearfield for this time period. From February through March, the water column was well mixed as shown for WN983. A weak temperature gradient was observed in April (WF984) and in May (WN985) temperatures had increased throughout the water column with a coincident increase in the vertical gradient. By mid-May (WN986), the nearfield water column was thermally stratified with surface temperatures of 10-12 °C in the upper 5 m (slightly higher at station N10) and bottom water temperatures of 6-8 °C at the nearshore stations and 4-6 °C at stations N15 and N04. Surface temperatures continued to increase reaching an average maximum surface temperature of 18 °C in July (WN988). By the end of July (WN989), surface temperatures had decreased in the nearfield. This may have resulted from summer upwelling events. The average bottom water temperature remained relatively stable (6-8°C) after establishment of stratified conditions.

As observed for temperature, the gradient between surface and bottom water salinity remained relatively weak (~1 PSU) until mid-May (Figure 4-19). Surface and bottom water salinity decreased 1-2 PSU from February to May. Following the early May survey (WN985), an increase in average bottom water salinity was observed for each successive survey. Surface water salinity, however, continued to decrease reaching a minimum during the June survey. The average surface water salinity in June was 25 PSU at these nearshore stations and 28 PSU at the outer nearfield stations. As mentioned above, these low salinity values resulted from input of freshwater to the nearfield surface waters from the June rain event and concomitant increases in runoff to the coastal waters. During the final two surveys in July, surface water salinity had returned to more typical values of approximately 30 PSU.

4.1.2 Transmissometer Results

Water column beam attenuation was measured along with the other *in situ* measurements at all nearfield and farfield stations. The transmissometer determines beam attenuation by measuring the percent transmission of light over a given path length in the water. The beam attenuation coefficient (m^{-1}) is indicative of particulate concentration in the water column. The two primary sources of particles in coastal waters are biogenic material (plankton or detritus) or suspended sediments. Beam attenuation data is often evaluated in conjunction with fluorescence data to ascertain source of the particulate materials (phytoplankton versus detritus or suspended sediments).

In early February (WF981) surface water beam attenuation ranged from 3.94 m^{-1} at station F23 located just outside the harbor to 0.76 m^{-1} at Boundary station F29. There was a clear decrease in beam attenuation from inshore to offshore with the elevated harbor signal being observed at the Inner Nearfield stations (Figure 4-20). During the second farfield survey in late February (WF982), surface water beam attenuation in Massachusetts Bay exhibited a similar decrease in values away from the harbor (2.29 m^{-1} at F30 to 0.70 m^{-1} at station F16). In Cape Cod Bay, however, elevated beam attenuation values at stations F01 and F02 (1.69 and 1.50 m^{-1}, respectively) were associated with the highest surface water fluorescence values observed during that survey (2.82 and 2.23 $\mu g L^{-1}$, respectively).

During the early April and June farfield/nearfield surveys (WF984 and WF987), beam attenuation in the surface water exhibited a similar decrease in values from inshore to offshore stations and was indicative of an increase in water clarity away from Boston Harbor. In April, the highest surface water beam attenuation values were found at the harbor stations (F23 and F30) and values decreased with distance from the harbor. In June, high surface water beam attenuation values were again observed at the harbor stations (2.01 – 3.12 m^{-1}), but elevated values were also observed at the inshore stations from Boston Harbor to Gloucester. Coincident fluorescence values were also higher at these coastal stations. The elevated beam attenuation and fluorescence values resulted from increased runoff (input of suspended sediments and potential source of nutrients) due to the heavy rains in June.

4.2 Biological Characteristics

4.2.1 Nutrients

Nutrient data were preliminarily analyzed using x/y plots of nutrient depth distribution, nutrient/nutrient relationships, and nutrient/salinity relationships (Appendix D). As with the physical characteristics, surface water contour maps (Appendix B) and vertical contours from select transects (Appendix C) were also produced from the nutrient data to illustrate the spatial variability of these parameters.

The most striking observation from the nutrient data for the first half of 1998 was the lack of a strong spring draw down of nutrients in the nearfield. A combination of physical and biological factors contributed to the extended period of replete nutrients in the spring of 1998. As mentioned in the previous section, seasonal stratification did not develop until May, thus for much of the spring the water column was well mixed supplying nutrients to the surface waters. Additionally, storms in late February may have contributed not only to the instability of the water column, but also to increased terrestrial runoff of nutrients into the bays. Finally, as discussed in Section 5, areal productivity was relatively low throughout the region, there was no winter/spring diatom bloom, and the abundance of phytoplankton remained < 10^6 cells L^{-1} until May, thus biological nutrient uptake was relatively low. The combination of physical instability and biological inactivity resulted in elevated nutrient concentrations in the surface waters throughout most of the region from February to June.

4.2.1.1 Horizontal Distribution

During this semi-annual period, the highest nutrient concentrations were consistently measured at the harbor and harbor influenced coastal and nearfield stations. Dissolved inorganic nutrients were generally at a maximum in surface waters during the first winter survey (WF981). By late February, ammonium and phosphate concentrations had decreased (except at the harbor and harbor influenced coastal stations) while relatively high concentrations of nitrate and silicate were still present in surface waters throughout the region. Similar nutrient conditions were observed in April: elevated concentrations at harbor and harbor influenced stations, low ammonium and phosphate concentrations throughout the region, and relatively high concentrations of nitrate and silicate in the nearfield and offshore. By June, however, nutrients were present in low concentrations (phosphate and ammonium at or near detection limits) throughout the region except for silicate in the nearfield and along the coast from Boston to Gloucester. These elevated silicate concentrations were due to heavy rains and the resulting runoff.

In early February (WF981), the highest nutrient values were found in Boston Harbor (Ammonia (NH_4) = 12.9 µM at station F31; Nitrate (NO_3) = 13.3 µM at station F30; Silicate (SIO_4) = 24.63 µM at station F30; Phosphate (PO_4) = 1.28 µM at station F31). The lowest concentrations were observed in Cape Cod bay at station F01 (NH_4 = 0.01 µM; NO_3 = 0.47 µM; SIO_4 = 0.61 µM; PO_4 = 0.09 µM). Nutrient concentrations generally decreased outside of the harbor and away from the coast (Figure 4-21). The low nutrient concentrations at station F01 coincided with elevated chlorophyll concentrations and phytoplankton abundance (centric diatoms dominant) and indicating that there may have been a winter bloom in Cape Cod Bay. The chlorophyll concentrations and phytoplankton abundance were, however, not high enough to have supported the observed nutrient drawdown, which suggests that the bloom event had occurred prior to the early February survey (WF981).

During the late February survey (WF982), the nutrient pattern was similar to WF981 with high concentrations in the harbor and along the south shore coastline then decreasing in the nearfield, Gloucester area, and offshore. In general, the nutrient concentrations in the surface waters had decreased since early February, but were still replete throughout the region.

In early April (WF984), the spatial pattern persisted with high concentrations in the harbor, a decrease in concentrations from inshore to offshore, and lower concentrations in Cape Cod Bay. Surface waters were replete in NO_3 and SiO_4 with concentrations for both of these nutrients ranging from ~2 to 8 µM outside of Boston Harbor (exception for NO3 at station F02 = 0.55 µM). A decrease from the February surveys in NH_4 (< 1 µM) and PO_4 (0.4 – 0.6 µM) concentrations was evident at the non harbor influenced stations, but the concentrations did not indicate that these nutrients were depleted from the surface waters.

During the beginning of June, New England experienced heavy rains. While this may have contributed to the continued high concentrations of nutrients in the harbor, most nutrients were depleted in the nearfield and farfield areas. Nitrate and phosphate were at or below detection limits throughout most of the nearfield and offshore areas (Figure 4-22). Silicate was the only parameter to exhibit an increase in concentration that correlated to the decrease in salinity (Figure 4-9) in the surface waters along the coast from Boston Harbor to Gloucester and most of the nearfield area (Figure 4-23). The impact of SiO_4 in association with runoff is clearly evident in Figure 4-23 as a sharp gradient begins offshore then cuts through the nearfield. The contour patterns observed in the data for salinity (Figure 4-9) and silicate (Figure 4-23) could be indicative of not only coastal runoff, but also the intrusion of a low salinity, SiO_4 rich plume from the northern rivers (e.g. Merrimack River). The major precipitation event occurred on June 13th approximately a week before the survey had a sufficient amount of time for the river plume to progress into Massachusetts Bay. Interestingly, the timing of sampling may have exaggerated the plume signal as the Cape Cod Bay stations and southern Massachusetts Bay stations were sampled on June 16th and 17th while the nearfield and northern stations were sampled on June 18, 19, and 20.

In July, the nearfield surveys (WN988 and WN989) documented low concentrations for all nutrients throughout the nearfield. Most surface water nutrient concentrations were less than 0.5 µM. These surface water concentrations indicate that the typical of the low nutrient, stratified water column summer conditions had developed by the end of this semi-annual period.

4.2.1.2 Vertical Distribution

Farfield. The vertical distribution of nutrients was evaluated using vertical contours of nutrient data collected along three transects in the farfield: Boston-Nearfield, Cohassett, and Marshfield (Figure 1-3; Appendix C). During the first combined farfield/nearfield survey in early February (WF981), the transect contours indicate that the water column was replete with nutrients. There was an inshore/offshore gradient of decreasing nutrient concentration for each of the nutrients. This pattern was most pronounced for the NH_4 data that clearly showed the harbor/coastal signal (Figure 4-24). In late February (WF982), similar inshore/offshore gradients were observed for each nutrient. In general, nutrient concentrations had decreased, but were still replete along each of the three transects.

By April (WF984), the vertical nutrient distribution had begun to change. There was still a clear inshore/offshore decrease in surface water nutrient concentrations and all nutrients were replete along each of the transects, but at the offshore stations there was an increase in NO_3, PO_4, and SiO_4 concentrations with depth (Figure 4-25). Though there had not been a significant winter/spring phytoplankton bloom (Section 5), the phytoplankton biomass was steadily increasing from February to April and nutrient concentrations were reduced in the surface waters while concentrations in the bottom waters remained relatively constant (NH_4 being the exception as Boston Harbor and the coastal inputs are the main sources for this nutrient).

During the combined farfield/nearfield survey in June, nutrient levels in the surface waters at the non-harbor-influenced stations were generally depleted. Ammonium concentrations still exhibited a strong harbor/coastal signal with a dominant inshore/offshore horizontal gradient of decreasing concentrations. Phosphate and nitrate were depleted in the surface waters along each of the transects, as was silicate except for the Boston-Nearfield transect where the heavy rains/runoff contributed to elevated concentrations along the coast and throughout most of the nearfield area (Figure 4-26). There was a strong vertical gradient for NO_3, PO_4, and SiO_4 along each of the transects.

Nutrient-salinity plots are useful in distinguishing water mass characteristics and in examining regional linkages between water masses (Appendix D). Dissolved inorganic nitrogen (DIN) plotted as a function of salinity for each of the combined surveys illustrates the transition from winter to summer nutrient conditions. During the February surveys, the DIN-salinity plot exhibited a negative correlation between DIN and salinity (Figure 4-27a). This relationship is indicative of winter conditions when the water column is not stratified and the harbor and coastal waters are a source of low salinity, nutrient rich waters. During the April survey (WF984), the winter signature was still present, but there also appears to be a slight increase in DIN concentrations at high salinity values (Figure 4-27b). Though stratification had not yet developed, an increase in nutrient uptake in the offshore surface waters led to a small vertical gradient in DIN with lower concentrations in the lower salinity surface waters and higher concentrations at depth. This suggests that this period is near the beginning of the transition period between winter and summer biogeochemical conditions. By June, the summer relationship between DIN and salinity is clearly evident (Figure 4-27c) though due to the heavy rain/runoff there are still a number of harbor and coastal stations where high DIN concentrations and low salinity were observed. The low DIN concentrations at low and intermediate salinity represent the surface waters throughout the Bays where biological activity has consumed DIN from both horizontal (harbor/coastal) and vertical (bottom waters) sources.

Nearfield. The nearfield surveys are conducted more frequently and provide a high resolution of the temporal variation in nutrient concentrations over the semi-annual period. In previous sections, the transition from winter to summer physical and nutrient characteristics has been discussed. For the nearfield, the transition from winter to summer nutrient regimes can be demonstrated by examining the variations in surface and bottom water SiO_4 and NO_3 concentrations. In Figures 4-28 and 4-29, surface and bottom water SiO_4 and NO_3 concentrations from five nearfield stations representing the four corners (N01, N04, N07, and N10) and the center (N21) of the nearfield were plotted for each of the nine surveys conducted this period. The highest concentrations were observed during the first combined survey in February. The concentrations of SiO_4 and NO_3 generally decreased over the course of this period, but no rapid decline was observed. During the first four surveys (February – April), there was little variation in SiO_4 and NO_3 between the surface and bottom waters at each station and the nearfield waters were replete with respect to these nutrients. Silicate, in fact, did not become depleted in the nearfield until July. Nitrate was depleted by mid-May at most of the nearfield stations except at the SW (station N10) and NE (station N04) corners of the nearfield which were not depleted until the June survey (WF987). These trends in SiO_4 and NO_3 in the nearfield support the observation that there was no winter/spring diatom bloom in the nearfield and corroborate the phytoplankton and biomass data that suggest there was a gradual increase in phytoplankton (primarily microflagellates and dinoflagellates) from February to June. Another interesting trend in Figure 4-29 is the dramatic increase in NO_3 concentrations in the bottom water from May/June to July. The increase in concentration in the bottom water is due to a combination of biological decomposition and nutrient regeneration processes.

Prior to the onset of stratified conditions in May, nutrient concentrations were relatively high. The highest concentrations were observed during the first survey in February and the values for over the nearfield were approximately 7-10 μM NO_3, 0-6 μM NH_4, 0.7-1 μM PO_4, and 8.5-12.5 SiO_4. Most of the variability in these ranges was due to the inshore/offshore decrease in concentrations. Over the course of the next three surveys, nutrient concentrations decreased, but none of the nutrients was depleted. By April (WF984), nutrient concentrations in the nearfield had decreased to approximately 2-6 μM NO_3, 0.5-2 μM NH_4, 0.3-0.8 μM PO_4, and 3-8 SiO_4.

During the May surveys (WN985 and WN986), NO_3, NH_4, and PO_4 were nearly depleted in the surface waters and were present at relatively low concentrations at depth (1-4 μM, 0-3 μM, 0.3-0.6 μM, respectively). Silicate, however, was present at moderate concentrations over the water column until June (~2-10 μM). By June, NO_3, NH_4, and PO_4 concentrations were generally at or below detection limits in the surface waters and remained that way through July. Silicate concentrations remained elevated throughout most of the nearfield in June due to the intrusion of high silicate, low salinity waters from coastal runoff. During the final two surveys in July, SiO_4 was also observed at relatively depleted concentrations. Additionally, as was observed with NO_3 (Figure 4-29), concentrations of PO_4 and SiO_4 below the pycnocline increased sharply from May/June to July.

The relationship of nutrients to salinity in the nearfield followed the trend discussed above for the whole region. For the July data, all of the nutrient-salinity plots exhibited the typical summer relationship of increasing nutrient concentrations with increasing salinity (and depth) and the lower salinity surface waters being depleted or nearly depleted of nutrients.

An examination of the nutrient-nutrient plots showed that surface waters were generally depleted in DIN relative to PO_4 and SiO_4 in the nearfield for the entire semi-annual period (Appendix D). During the first three surveys, the DIN:PO_4 ratio was approximately equal to the Redfield value of 16 at some of the harbor-influenced stations. For the remaining stations and surveys, the ratio of DIN:PO_4 was less than 16 and decreased from 8-10 during the first four surveys prior to stratification of the nearfield water column (February – April) to <4 during the final five surveys.

4.2.2 Chlorophyll A

Chlorophyll concentrations (based on *in situ* fluorescence measurements) were generally low during the earlier surveys and increased over the course of the period. The main exceptions was the regional maximum concentrations observed during WF984 for subsurface waters in Cape Cod Bay (17.0 μgL^{-1}) and the coastal area (15.3 μgL^{-1}). Maximum chlorophyll values for the Boundary, Boston Harbor, and Offshore areas were observed during WF987. The maximum values observed during each survey in the nearfield increased from 0.83 μgL^{-1} in early March (WF982) to 18.7 μgL^{-1} in late July (WN989).

4.2.2.1 Horizontal Distribution

Surface chlorophyll concentrations were generally low throughout the region during the first two surveys of 1998 (WF981 and WF982). Due to an instrument malfunction, we did not collect *in situ* fluorescence data in early February (WF981), but the chlorophyll concentrations from laboratory extractions were all less than 1 μgL^{-1}. Chlorophyll concentrations were > 0.6 μgL^{-1} in the Harbor (F23 and F24), at a few nearfield stations, and at station F01 in Cape Cod Bay. In late February (WF982), elevated chlorophyll concentrations were observed in southern Cape Cod Bay (2-3 μgL^{-1}) and Boston Harbor (~1 μgL^{-1}). Surface chlorophyll concentrations were less than 1 μgL^{-1} throughout the rest of the region.

By early April (WF984), chlorophyll concentrations had increased with high concentrations being observed at the western Cape Cod Bay, Coastal, Boston Harbor, and northern Boundary stations (Figure 4-30). Relatively low chlorophyll levels were observed at the Offshore and eastern Cape Cod Bay stations (1-2 mgL^{-1}). The phytoplankton identifications indicate that there were elevated numbers of chain-forming and centric diatoms in Cape Cod Bay and suggest a coastal spring diatom bloom. Microflagellates were the dominant phytoplankton in Massachusetts Bay and continued to increase in abundance (and chlorophyll concentration) from the February surveys.

By mid-June (WF987), the phytoplankton assemblage throughout the farfield was dominated by chain-forming diatoms. The general pattern in surface chlorophyll was similar to that observed in early April. The chlorophyll concentrations at the Coastal and Boston Harbor stations were relatively high ranging from 5 to 13 μgL^{-1} (Figure 4-31). There was a clear decrease in surface chlorophyll concentration from the inshore to the offshore stations. This was also evident within the nearfield with higher chlorophyll concentrations found to the north and west and lower concentrations to the southeast. The pattern observed in surface water chlorophyll closely followed the pattern of surface salinity (Figure 4-9).

4.2.2.2 Vertical Distribution

Farfield. The chlorophyll concentrations over the water column were examined along the three east/west farfield transects (Figure 1-3) to compare the vertical distribution of chlorophyll across the region. As mentioned previously, there were no fluorescence data for WF981, but laboratory data for extracted chlorophyll indicated that concentrations were low throughout the region (<1 μgL^{-1}). During WF982, the chlorophyll concentrations along the transects were generally low (<2 μgL^{-1}) except at Coastal station F05 and there was an inshore to offshore decrease in chlorophyll. As with the physical properties, the water column was well mixed in regard to chlorophyll concentrations.

In April (WF984), chlorophyll concentrations were higher ranging from <2 to 15 μgL^{-1} along the three transects. The highest concentrations were observed nearshore at station F05 and there was generally a decrease in chlorophyll from inshore to offshore with the exception being elevated concentrations in the surface waters at station F27 along the Boston-Nearfield transect. The chlorophyll maximum was observed in both surface and subsurface waters along the Boston-Nearfield transect while a subsurface maximum was seen along the Cohassett and Marshfield transects. None of the maxima were sharply defined layers, but rather broad zones (10-20 m) of elevated chlorophyll concentrations.

Chlorophyll concentrations during the June survey were the highest observed on these transects and covered a wide range of values (<2 to 26.6 μgL^{-1}). Subsurface chlorophyll maxima were observed along each of the transects except at the harbor influenced station F23. The surface and near-surface chlorophyll concentrations were relatively high along the Boston-Nearfield transect from station F23 to station N21 (Figure 4-32). The elevated chlorophyll values at these nearshore stations closely follow the incursion of low salinity water that was observed during this survey (see Figure 4-15). The subsurface chlorophyll maximum that was observed at the offshore stations along the Boston-Nearfield transects and along the Cohassett and Marshfield transects appears to be associated with the higher salinity water near the pycnocline. It is unclear whether the phytoplankton communities associated with the lower and higher salinity waters were different, but the gross taxonomic data indicate that similar assemblages (see Figure 5-16; dominated by centric diatoms) were present at the four stations along these transects that phytoplankton samples were collected (F23, F24, N16, and F06).

Nearfield. The vertical distribution of chlorophyll was examined along a transect from the southwest corner to the northeast corner of the nearfield area (see Figure 1-3). The southwest corner, station N10, often exhibits a harbor chlorophyll signal while an offshore chlorophyll signal is more often observed at the northeast corner, station N04. Chlorophyll concentrations were relatively low (<1 μgL^{-1}) in early March (WF982) along the nearfield transect. On March 24th (WN983), a subsurface chlorophyll max (1-3 μgL^{-1}) was observed at a depth of approximately 10 meters across the nearfield transect with concentrations of > 3 μgL^{-1} at station N19 (Figure 4-33).

In early April (WF984), elevated chlorophyll concentrations (1-3 μgL^{-1}) were present over the upper 10 m of the water column at the harbor-influenced station N10. This harbor chlorophyll signal was also observed as a subsurface chlorophyll max at 10-15 m along the rest of the nearfield transect. By May 1st (WN985), the water column in the nearfield was beginning to stratify and nutrient concentrations in the surface waters had decreased. Chlorophyll concentrations in the upper 20 m of the water column were low (<1 μgL^{-1}) while the concentrations below the pycnocline ranged from 3-7 μgL^{-1}. This chlorophyll distribution represents either localized production at depth or sinking phytoplankton. Based on the productivity data (see Appendix E), it appears that the high subsurface chlorophyll concentrations resulted from localized production that was coincident with elevated nutrient concentrations. By mid May (WN986), the range of chlorophyll concentrations was similar, but the vertical distribution of chlorophyll had changed. A subsurface chlorophyll maximum of 1-5 μgL^{-1} was observed across the transect at 5-10 m (Figure 4-34). Surface water concentrations were <1 μgL^{-1} at every station except N10.

In mid-June (WF987), chlorophyll concentrations had increased to 1-3 μgL^{-1} along the most of the nearfield transect with elevated concentrations being found in the surface waters at stations N15 and N04 (3-5 μgL^{-1}), and N10 (3-9 μgL^{-1}). Higher concentrations continued to be observed at station N10 relative to the rest of the transect during both of the July surveys (WN988 and WN989). In mid-July, chlorophyll concentrations reached 9-11 μgL^{-1} in the upper 15 meters of the water column at station N10 at the subsurface maximum at 5-10 meters. The subsurface maximum in chlorophyll concentration extended over the entire transect with concentrations of 1-3 μgL^{-1} observed at a depth of 5-10 meters at stations from N19 to N04. In late July, chlorophyll concentrations were relatively high in the upper 15 m at stations N10, N15, and N21 and a subsurface chlorophyll maximum of >9 μgL^{-1} was observed at approximately 5 m for the two inshore stations. At the offshore stations (N15 and N04), chlorophyll concentrations were <2 μgL^{-1} over most of the water column except for a layer at about 15 m where concentrations of 5-9 μgL^{-1} (station N15) and >11 μgL^{-1} (station N04) were observed.

4.2.3 Dissolved Oxygen

Spatial and temporal trends in the concentration of dissolved oxygen (DO) were evaluated for the entire region (Section 4.2.3.1) and for the nearfield area (Section 4.2.3.2). Due to the relative importance of identifying low DO conditions, bottom water DO minima were examined for the water sampling events. The minimum measured DO concentration was 6.83 mgL^{-1} in the nearfield in July (WN989). Regionally, a DO concentration minimum of 8.43 mgL^{-1} was observed in the offshore area in late February (WF982). DO concentrations were generally higher than usual for the late spring and early summer in 1998. Due to the late onset of stratification and the lack of a winter/spring phytoplankton bloom, the relatively high bottom water DO concentrations are not surprising and this trend may continue through the remainder of 1998.

4.2.3.1 Regional Trends of Dissolved Oxygen

The DO of bottom waters was compared between areas and over the course of the four combined surveys. A time series of the average bottom water DO concentration for each area is presented in Figure 4-35a. Average bottom water DO concentrations ranged from 9.8 to 11.7 mgL^{-1}. After a slight decrease in bottom water DO from the February/March surveys to the April survey, an increase in these values was observed during the final combined survey. The normal trend is for DO to generally decline in the bottom waters from February to June, but, consistent with the lack of a winter/spring phytoplankton bloom and the increased productivity observed during the WF987 survey, bottom water DO concentrations were higher throughout most of the farfield region in June. In Cape Cod Bay, the average bottom water DO concentrations were slightly lower in June than during the previous surveys, though there was little change in these values during this reporting period in this area.

The trend of increasing DO in the bottom waters was even more apparent in the DO %saturation data (Figure 4-35b). For each of the areas, the highest average DO % saturation was observed during the June survey. The bottom waters were supersaturated with respect to DO in June with average values ranging from 102-120 % saturation.

In February, the spatial distribution of DO generally exhibited an inshore to offshore trend of decreasing DO concentrations along the three regional transects. In April, the onset of seasonal stratification led to lower DO concentrations in the bottom waters along each of the transects (Figure 4-36. By June, however, high DO concentrations (>11 mgL^{-1}) were observed throughout the water column (Figure 4-37). The elevated DO concentrations were coincident with the highest chlorophyll concentrations and productivity observed for the farfield region.

4.2.3.2 Nearfield Trends of Dissolved Oxygen

Dissolved oxygen concentrations and percent saturation values for both the surface and bottom waters of the 21 nearfield stations were averaged and plotted for each of the nearfield surveys. There was less than a 1 mgL^{-1} difference between the surface and bottom water DO concentration for all but the last survey (Figure 4-38a). From February to early July, the average surface and bottom water concentrations for the nearfield area generally ranged from 10-11 mgL^{-1}. In late July, there was a 3 mgL^{-1} gradient in DO concentrations between the surface and bottom waters and the average surface water DO concentration in July (11.7 mgL^{-1}) was the highest observed during this period.

There was little variation in the average DO %saturation for the surface and bottom waters for the first three surveys of 1998 (Figure 4-38b). With the onset of stratification in April (WF984), the gradient between surface and bottom water %saturation began to increase and the actual values had decreased reaching the lowest average %saturation for both surface (102%) and bottom (91%) waters. A large increase in DO concentration and %saturation was observed between the May and June surveys. This increase was probably the result of a combination of factors: the major rain event that occurred in mid June and the continuation of the high productivity measured in May (WN986). The gradient between surface and bottom water %saturation increased from June through July as surface %saturation remained high and bottom water %saturation decreased.

The large gradients in DO concentration and %saturation observed in July resulted from a combination of physical and biological factors. By June (WF987), the nearfield water column was strongly stratified separating the biological and chemical processes of the surface and bottom waters. The elevated surface water DO concentration and %saturation in July was contaminant with generally high chlorophyll concentrations and high phytoplankton abundance while the decrease in bottom water DO concentrations was coincident with an increase in respiration rates in July.

4.3 Summary of Water Column Results

- The establishment of a stratified water column occurred later than usual in 1998. Regional seasonal stratification was not observed until the June survey (WF987), though the onset of stratification was suggested by the data collected in April (WF984).
- In the nearfield area, the data indicated that the stable pycnocline associated with seasonal stratification was developing in early May, but that stratified water column conditions were not established in the nearfield until the middle of May.
- A significant rain event occurred prior to the June farfield/nearfield survey (WF987). As a result of the rainfall and concomitant increase in runoff, very low salinity surface waters were

observed along the coast from Boston to Gloucester and into the northern and eastern portion of the nearfield. In these areas, the presence of low salinity surface waters served to intensify the already established water column stratification.

- The most striking observation from the nutrient data for the first half of 1998 was the lack of a strong spring draw down of nutrients in the nearfield. A combination of physical and biological factors contributed to the extended period of replete nutrients in the spring of 1998.
  - Seasonal stratification did not develop until May, thus for much of the spring the water column was well mixed supplying nutrients to the surface waters.
  - Storms in late February may have contributed not only to the instability of the water column, but also to increased terrestrial runoff of nutrients into the bays.
  - Productivity was relatively low throughout the region, there was no winter/spring diatom bloom, and the abundance of phytoplankton remained < 10^6 until May, thus biological nutrient uptake was relatively low.
- The highest nutrient concentrations were consistently measured in Boston Harbor and at the harbor-influenced coastal and nearfield stations.
- Dissolved inorganic nutrients were generally at a maximum in surface waters during the first winter survey, present at non-limiting concentrations from February to May, and depleted or nearly depleted in June and July.
- Chlorophyll concentrations were generally low during the earlier surveys and increased over the course of the period with the highest chlorophyll values being observed in June. The main exceptions being the regional maximum concentrations observed in April for subsurface waters in Cape Cod Bay and the coastal area.
- In the nearfield area, the highest chlorophyll concentrations were observed in mid May (WN986). For this survey, the distribution of chlorophyll suggested a harbor or coastal influence with productive phytoplankton and/or nutrients being transported offshore to the nearfield area.
- DO water concentrations were generally higher than usual for the late spring and early summer in 1998. The normal trend is for DO to generally decline in the bottom waters from February to June, but the relatively high DO concentrations observed are consistent with the other physical and biological data.
  - The delay in establishment of seasonal stratification – continued communication between surface and bottom waters during much of this period.
  - The lack of a winter/spring phytoplankton bloom – limited supply of organic material to the bottom waters until late spring/summer.
  - The increased productivity during the May and June surveys – biological production of oxygen over much of the water column.
- Typical summer vertical DO gradients were observed in the nearfield area in July. These gradients resulted from a combination of physical and biological factors.
  - By June, the nearfield water column was strongly stratified separating the biological and chemical processes of the surface and bottom waters.
  - The elevated surface water DO concentration in July was contaminant with generally high chlorophyll concentrations and high phytoplankton abundance
  - The decrease in bottom water DO concentrations was coincident with an increase in respiration rates in July.

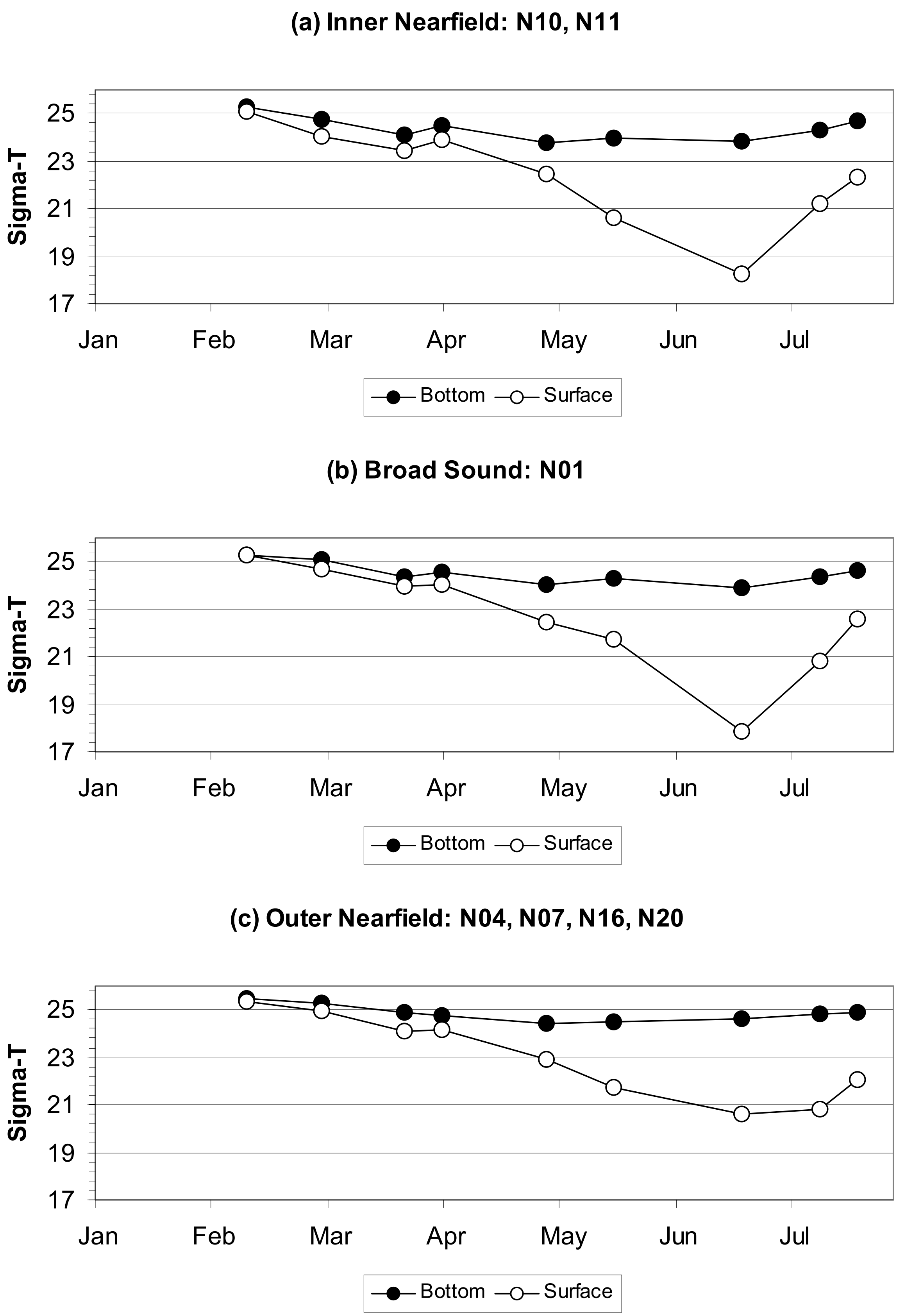


Figure 4-1. Time-Series of Average Surface and Bottom Water Density (σ_t) in the Nearfield

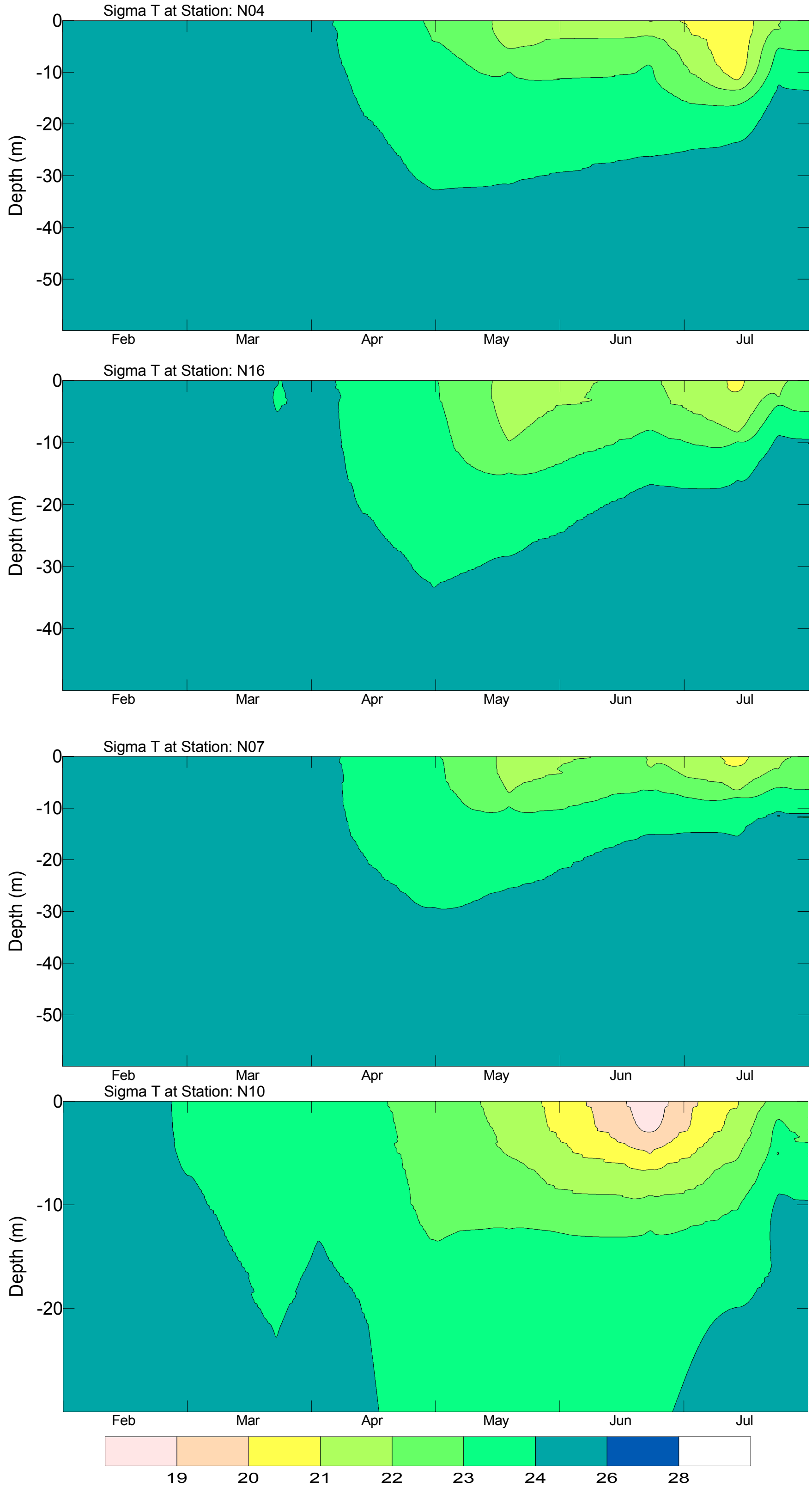


Figure 4-2. Sigma-T Nearfield Transect Depth vs. Time Contour Profiles for Surveys WF981 through WN989

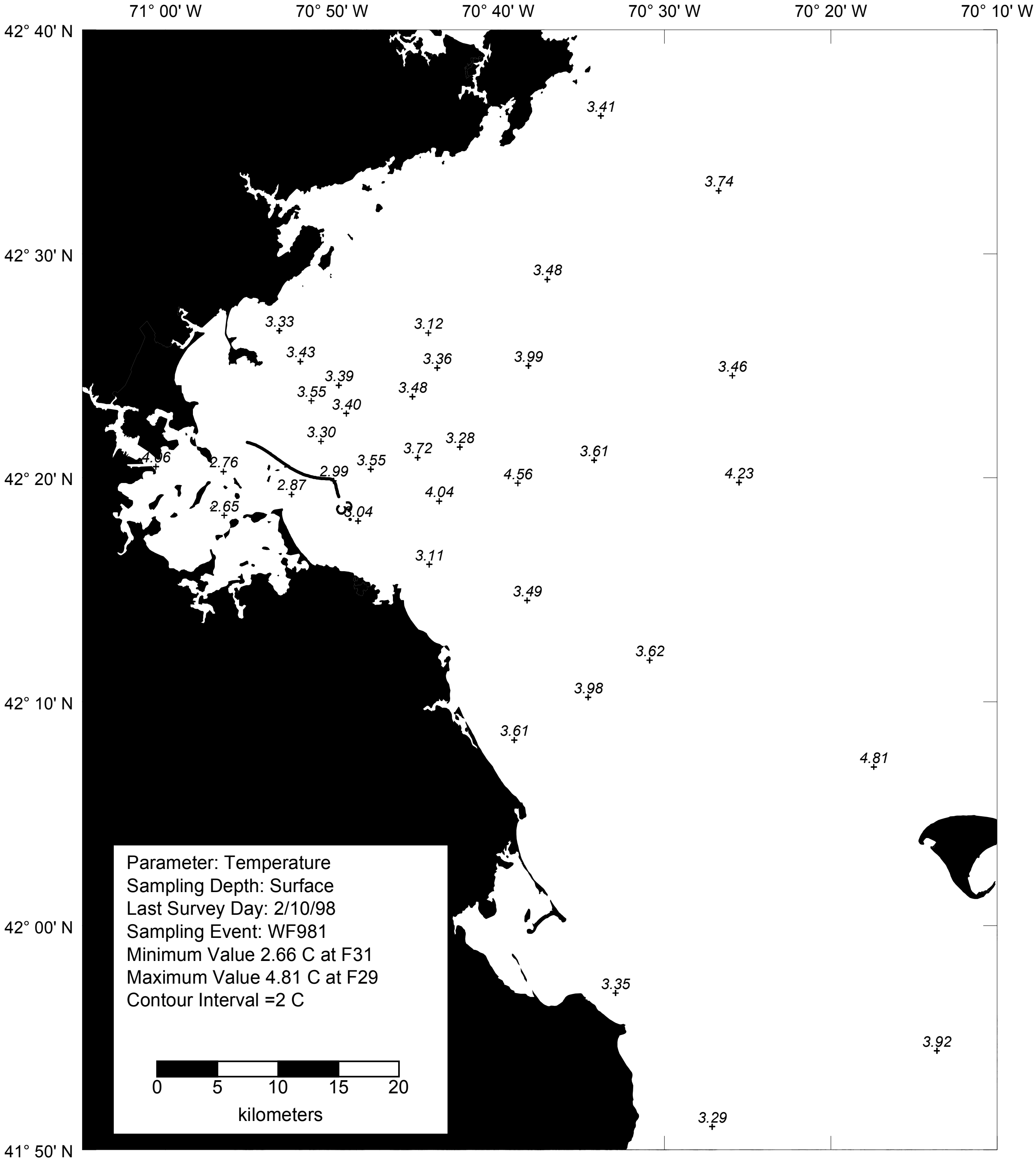


Figure 4-3. Temperature Surface Contour Plot for Farfield Survey WF981 (Feb 98)

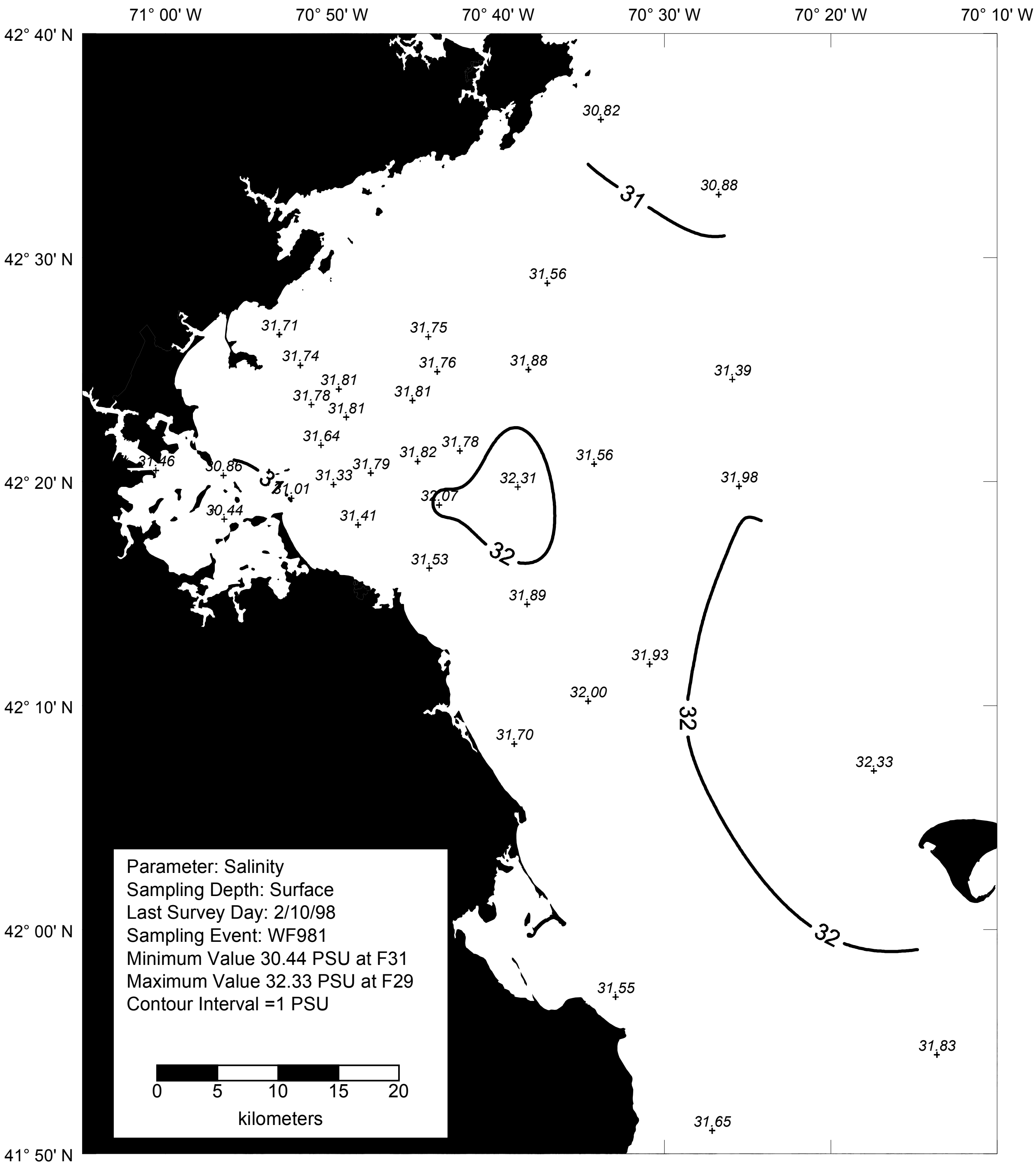


Figure 4-4. Salinity Surface Contour Plot for Farfield Survey WF981 (Feb 98).

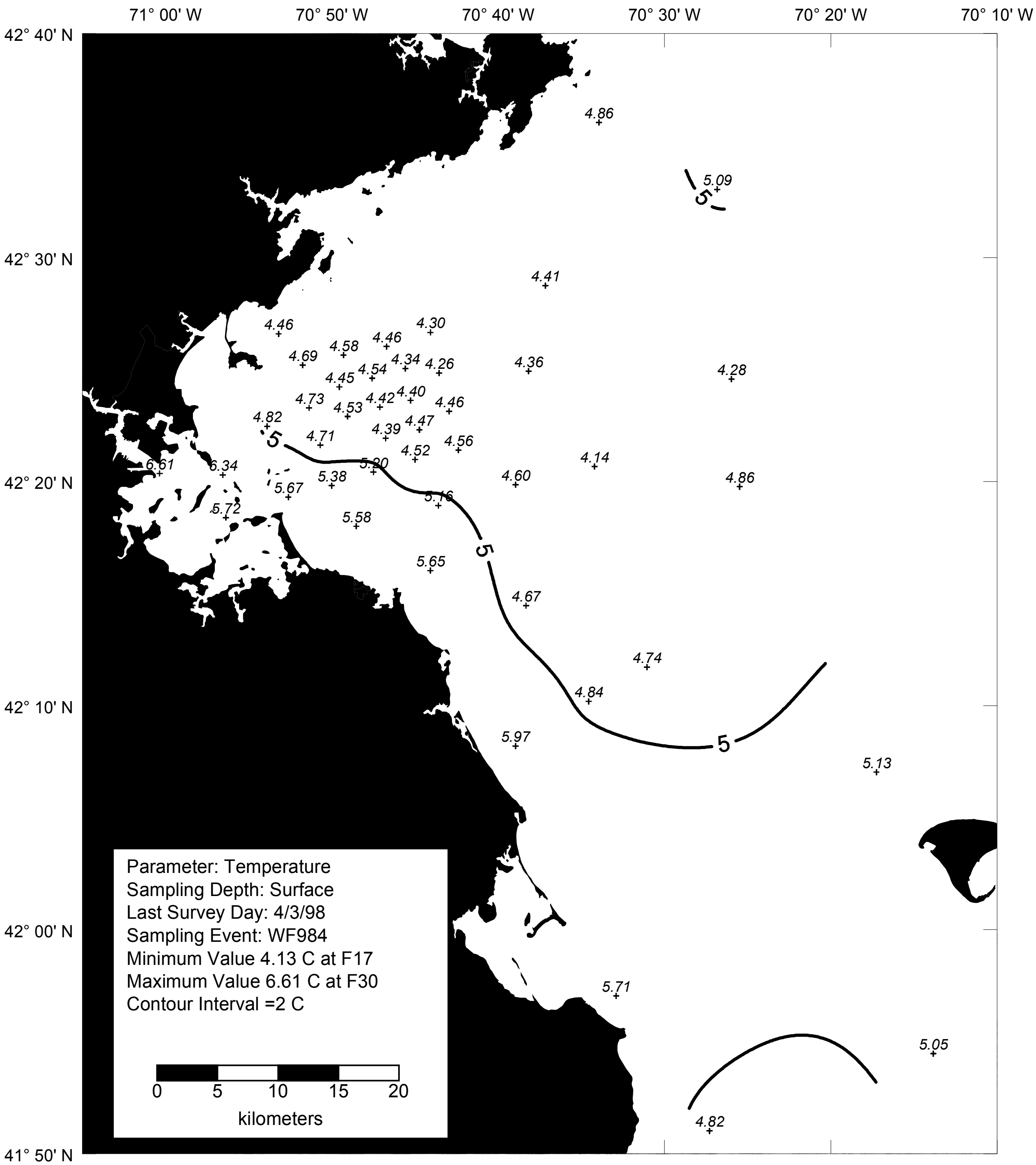


Figure 4-5. Temperature Surface Contour Plot for Farfield Survey WF984 (Apr 98)

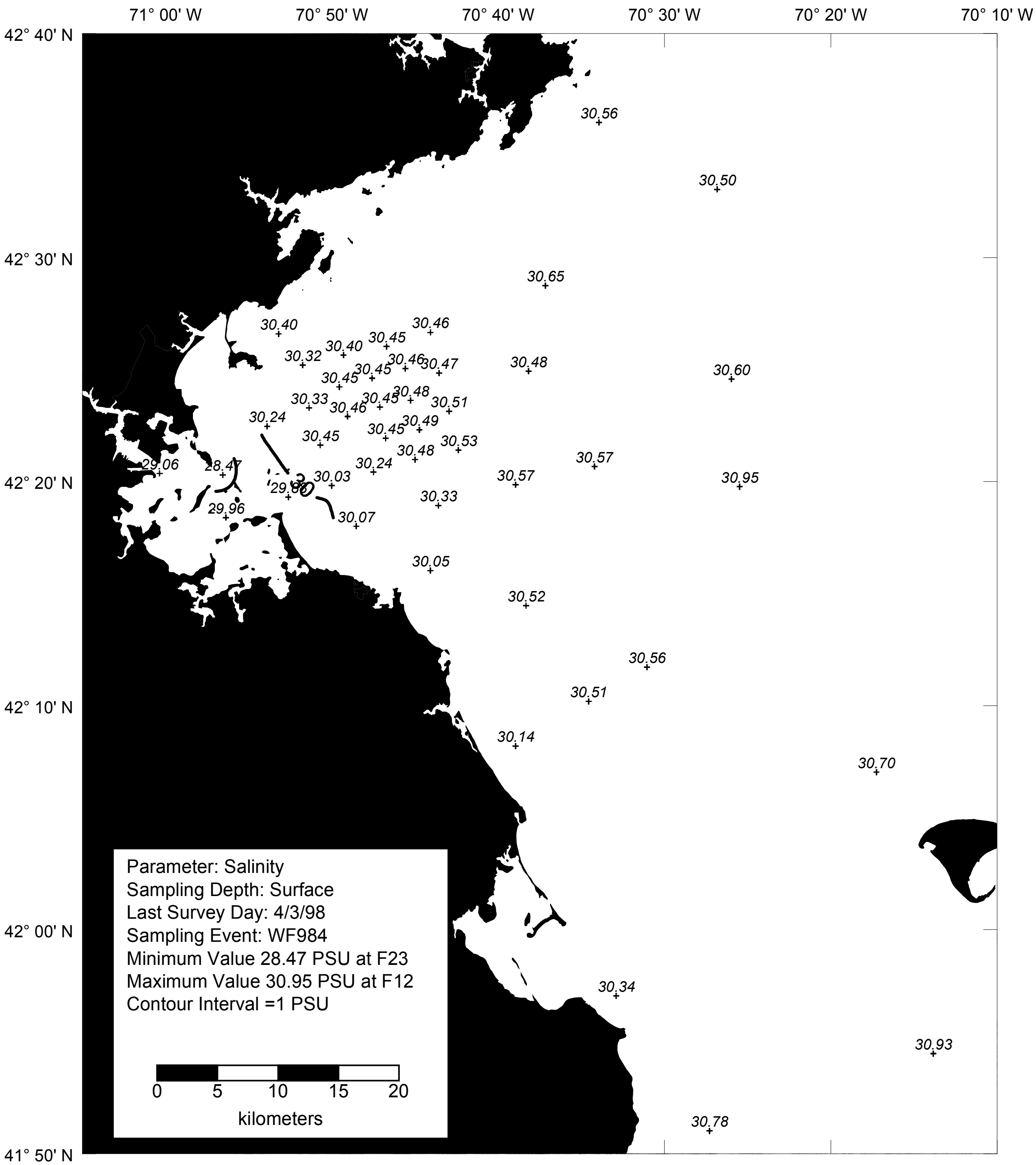
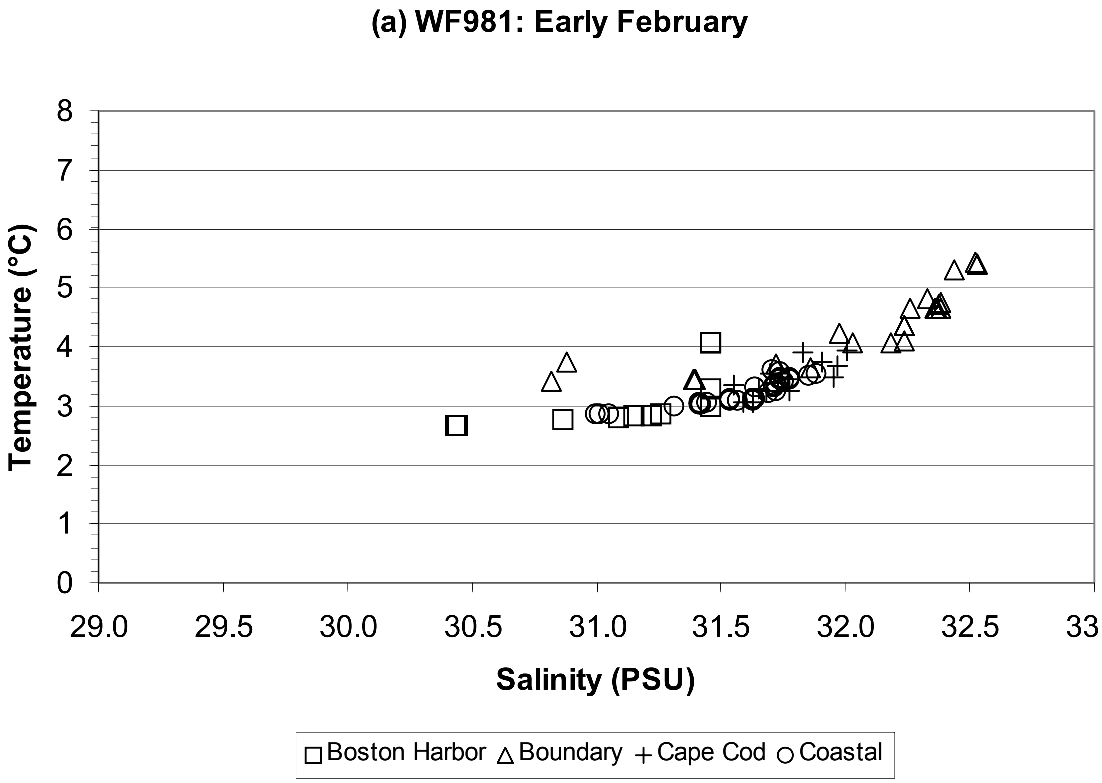


Figure 4-6. Salinity Surface Contour Plot for Farfield Survey WF984 (Apr 98)



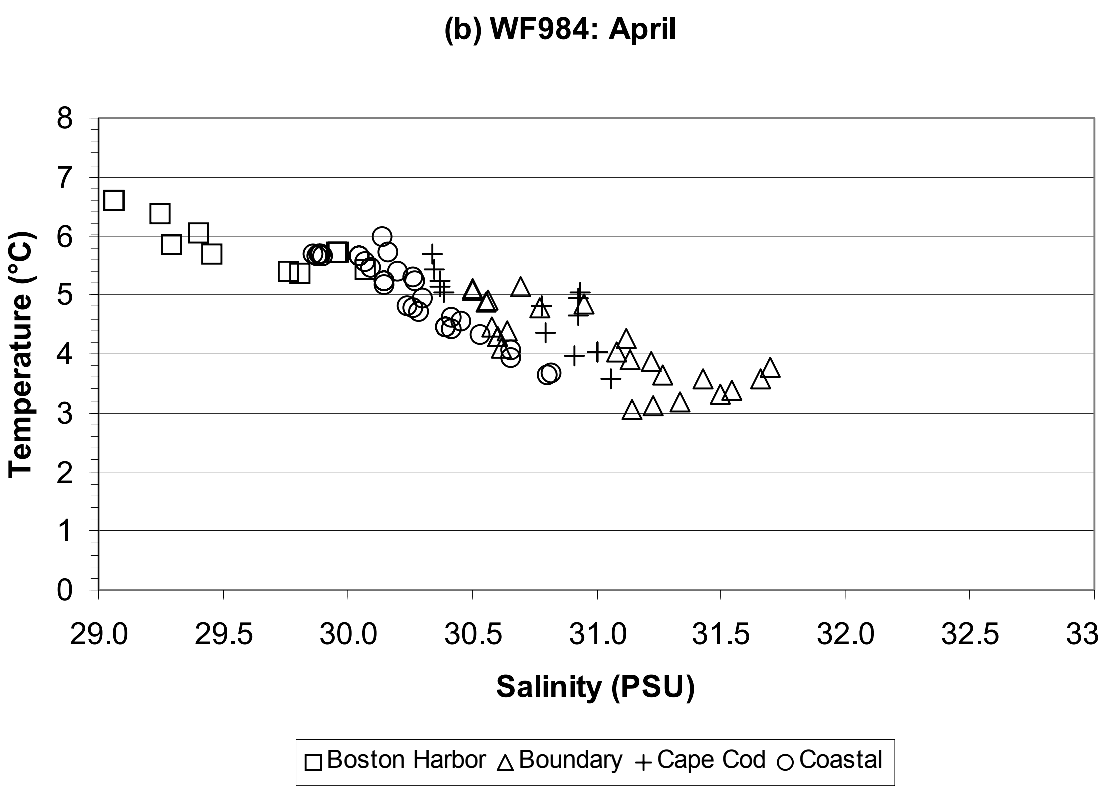


Figure 4-7. Temperature/Salinity Distribution for All Depths during WF981 (Feb 98) and WF984 (Apr 98) Surveys

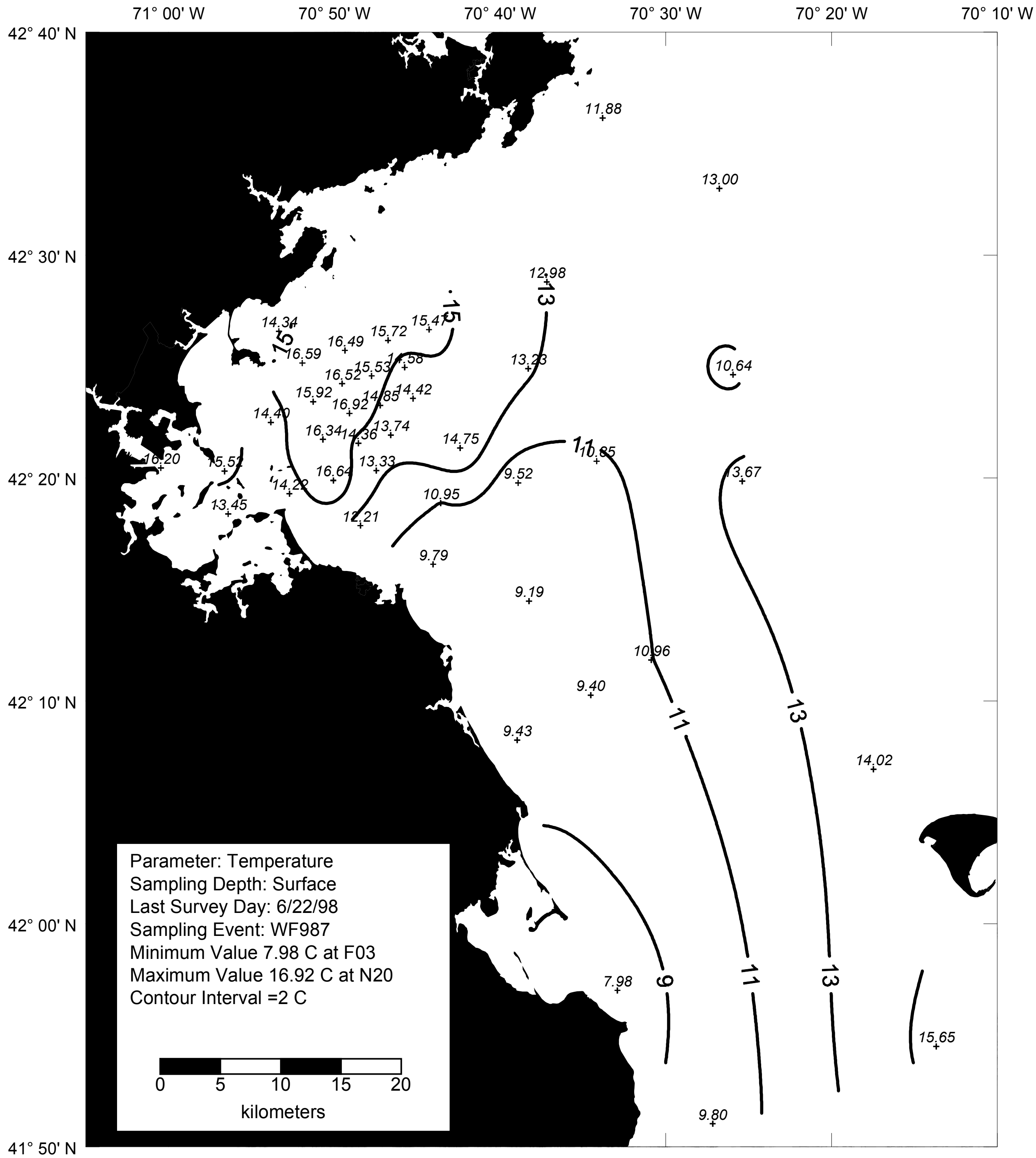


Figure 4-8. Temperature Surface Contour Plot for Farfield Survey WF987 (Jun 98)

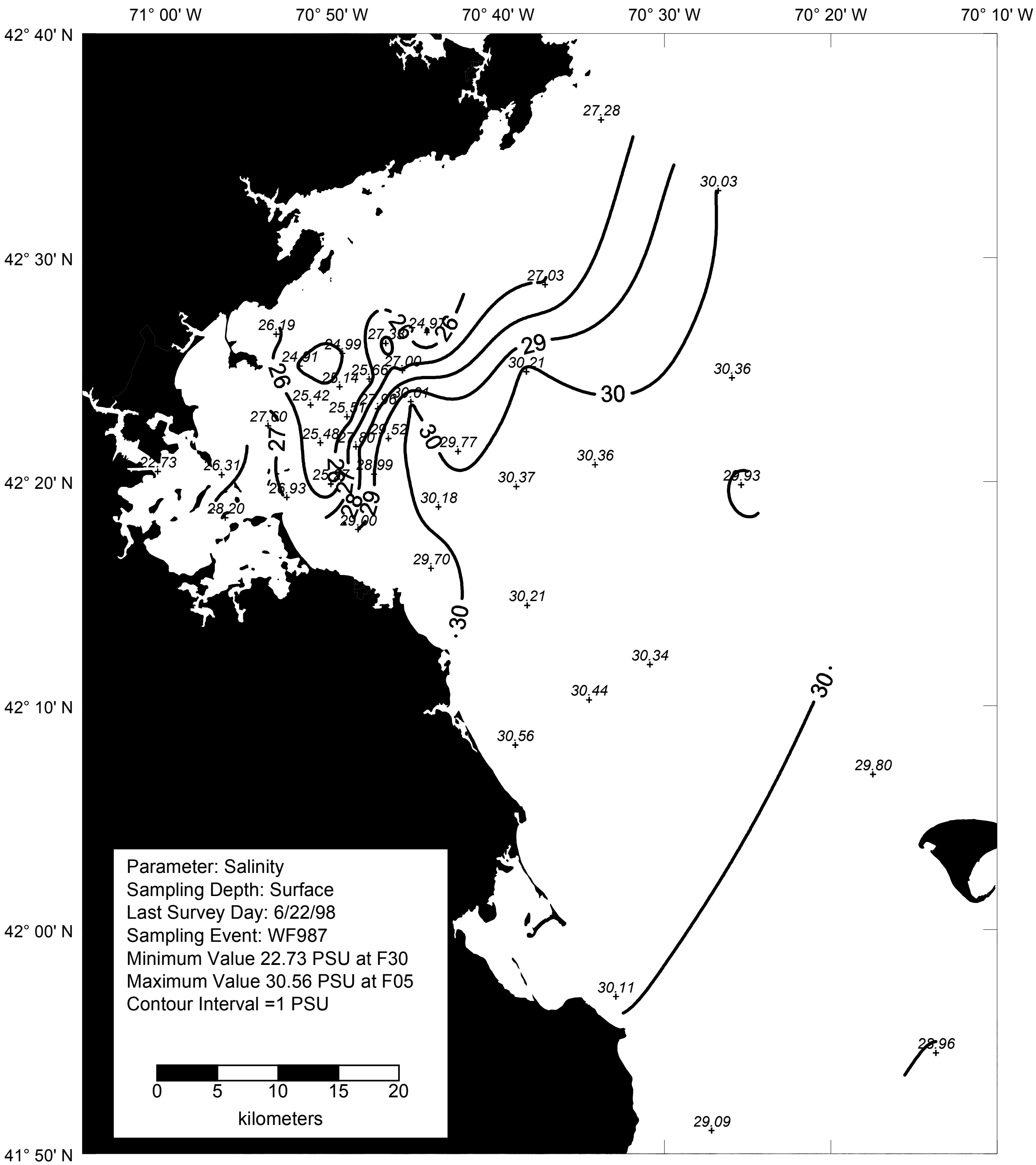


Figure 4-9. Salinity Surface Contour Plot for Farfield Survey WF987 (Jun 98)

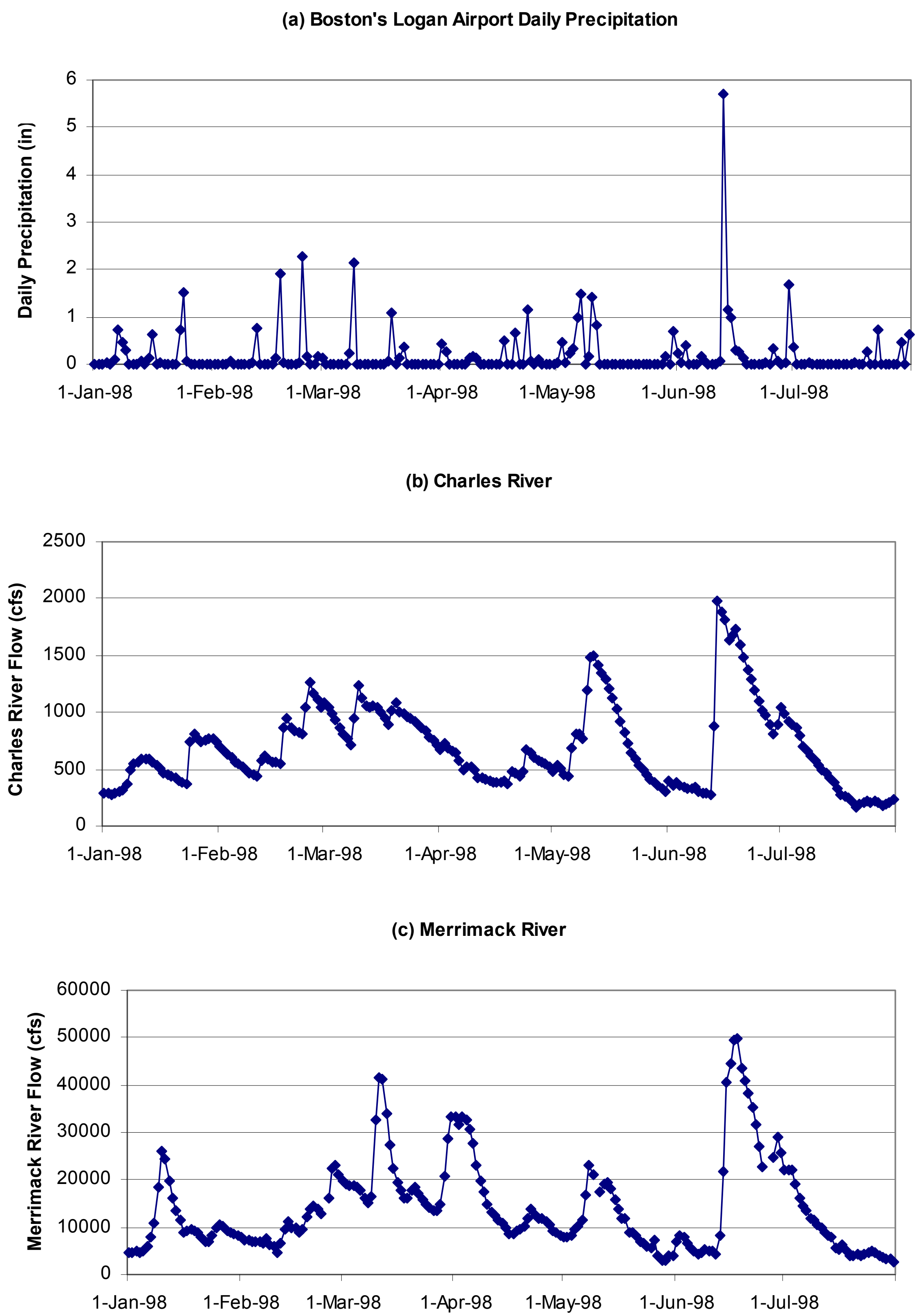


Figure 4-10. Precipitation at Logan Airport and River Discharges for the Charles and Merrimack Rivers

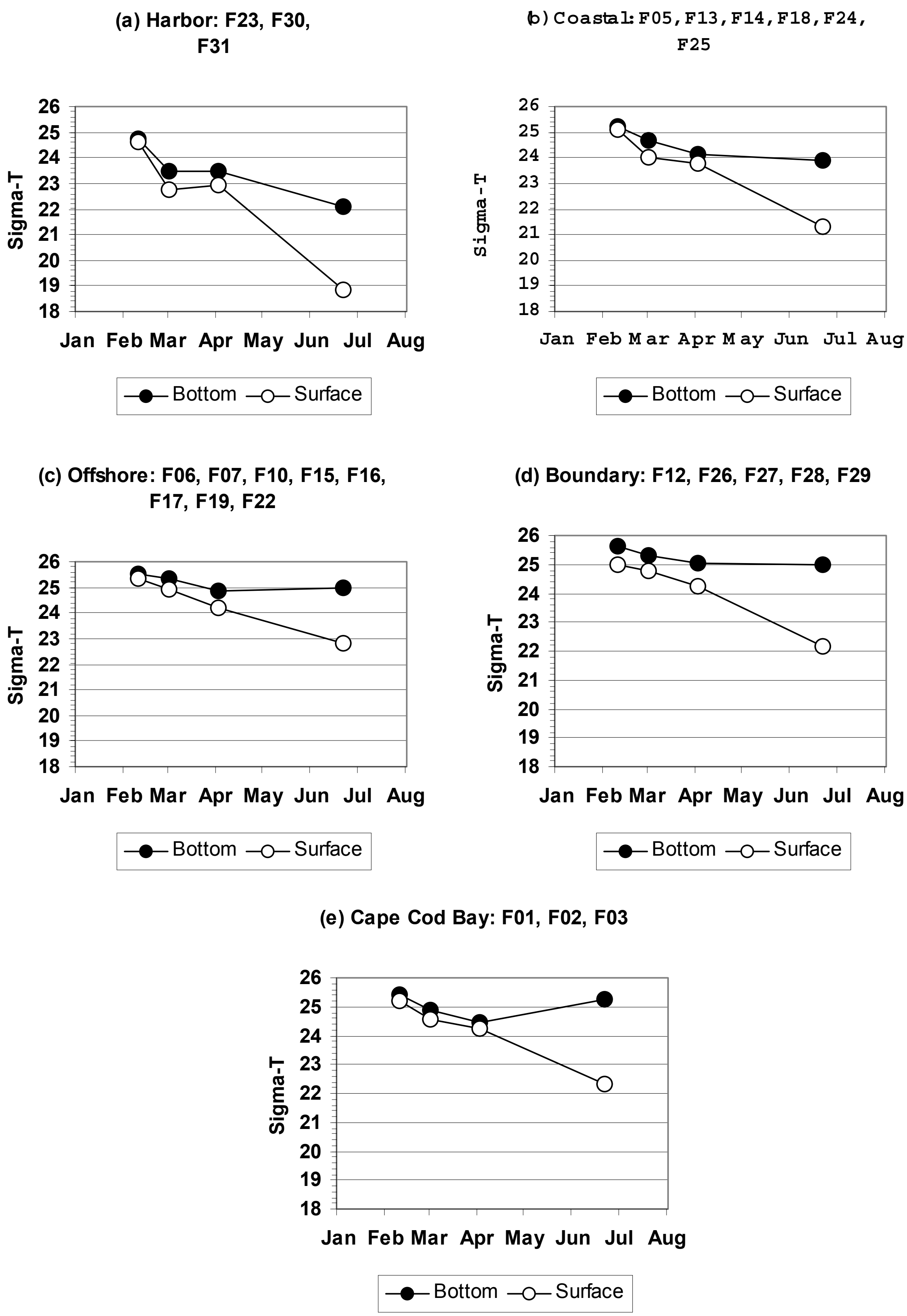


Figure 4-11. Time-Series of Average Surface and Bottom Water Density (σ_T) in the Farfield

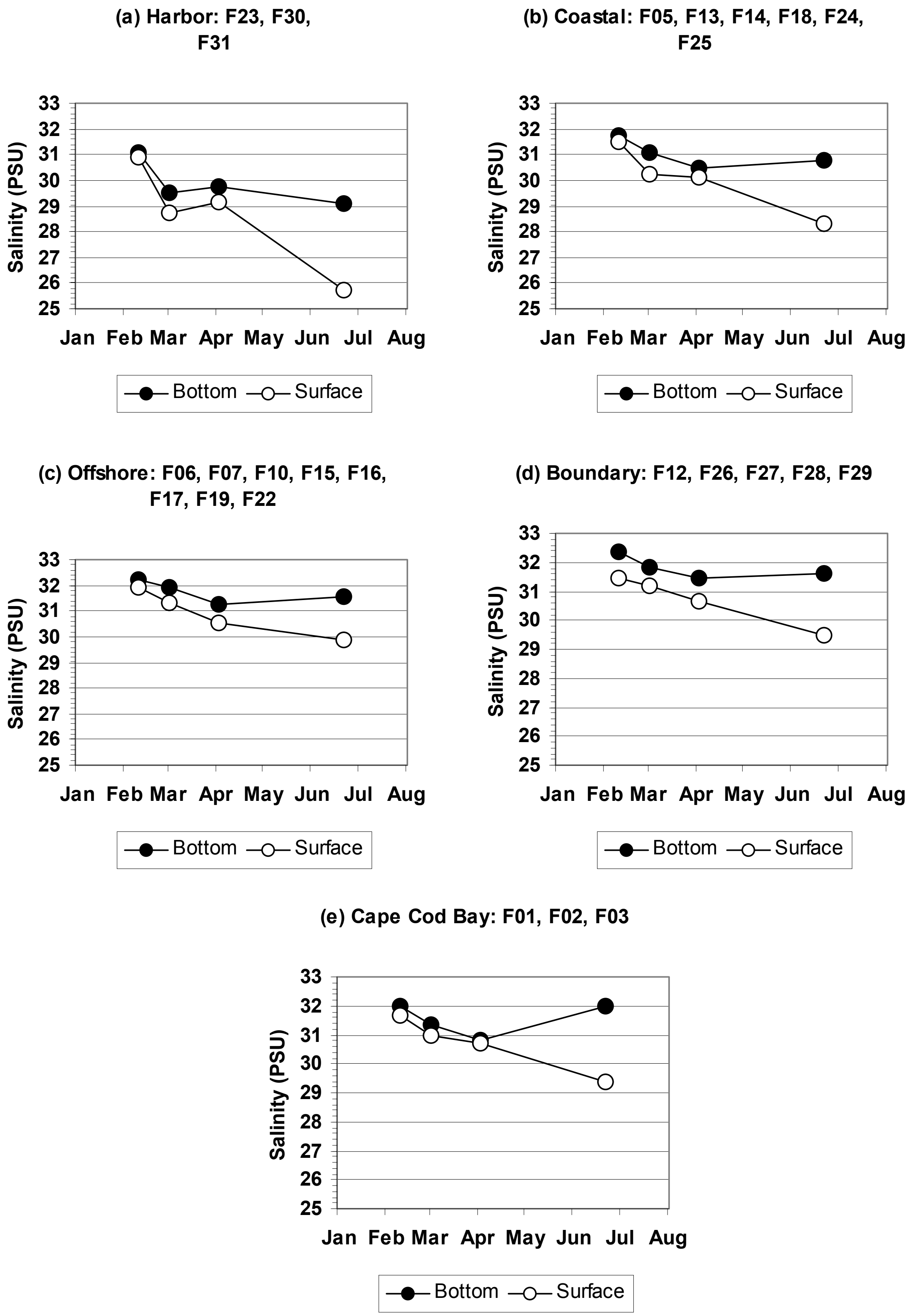


Figure 4-12. Time-Series of Average Surface and Bottom Water Salinity (PSU) in the Farfield

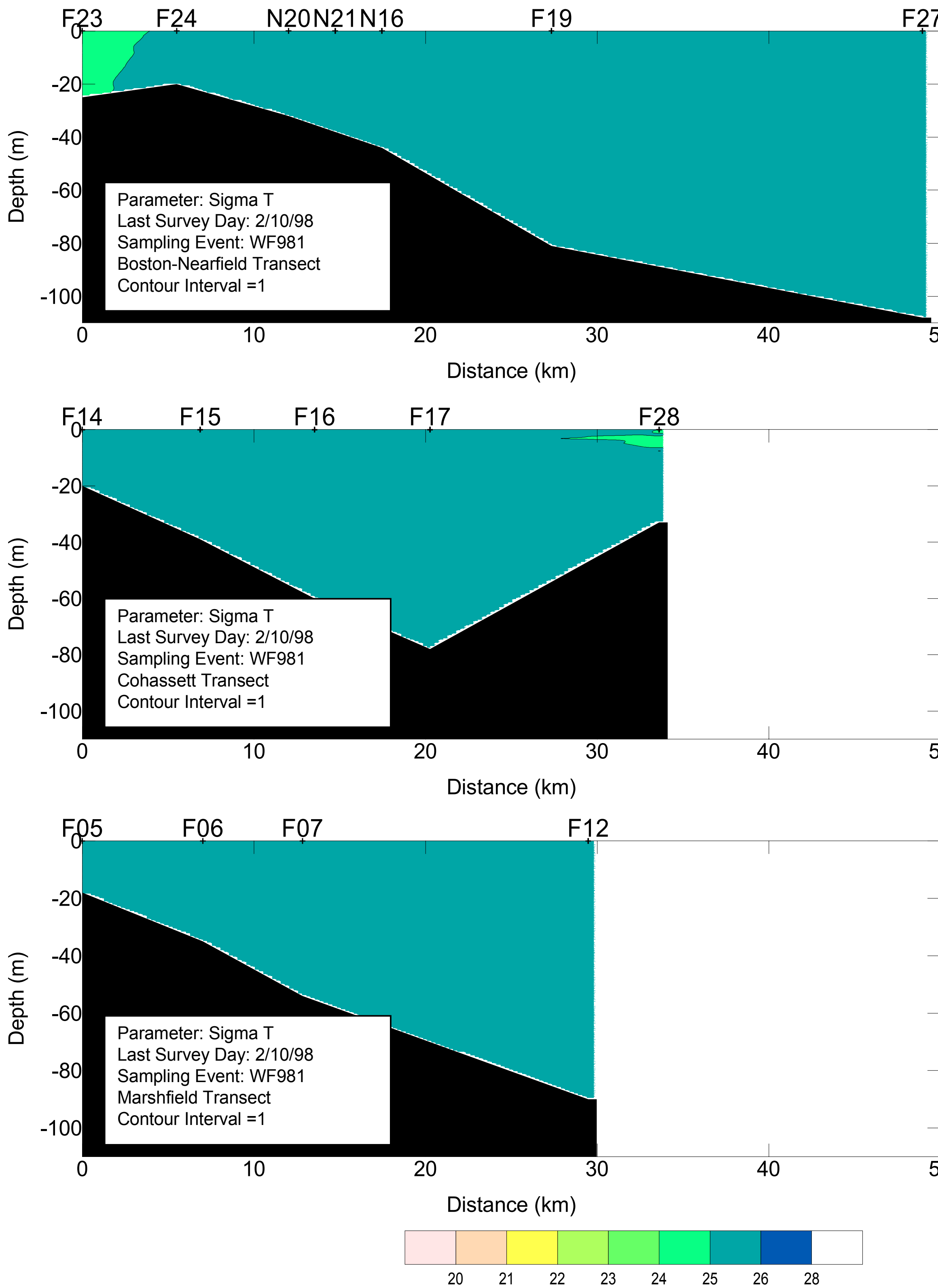


Figure 4-13. Sigma-T Vertical Transects for Farfield Survey WF981 (Feb 98)

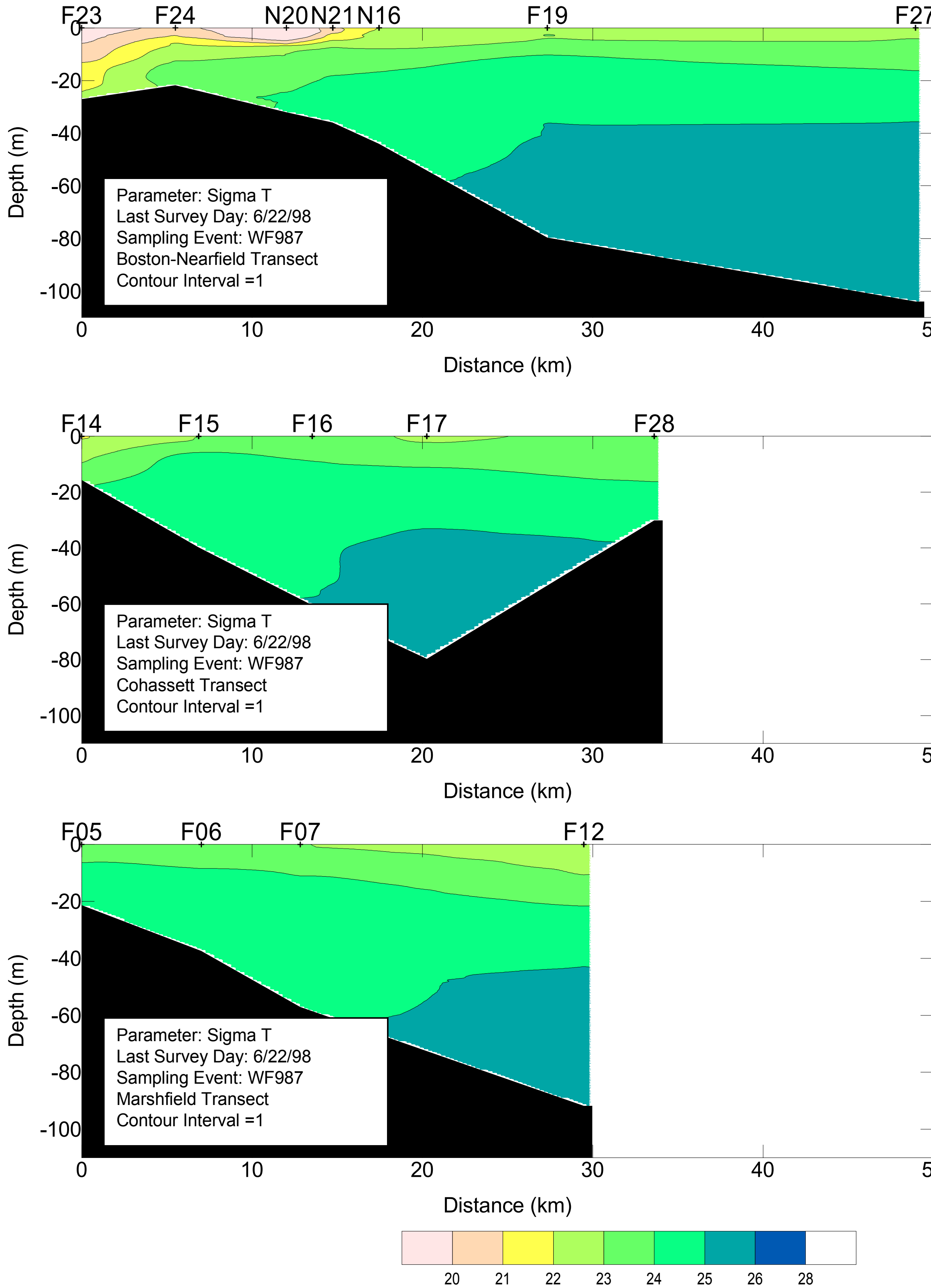


Figure 4-14. Sigma-T Vertical Transect for Farfield Survey WF987 (Jun 98)

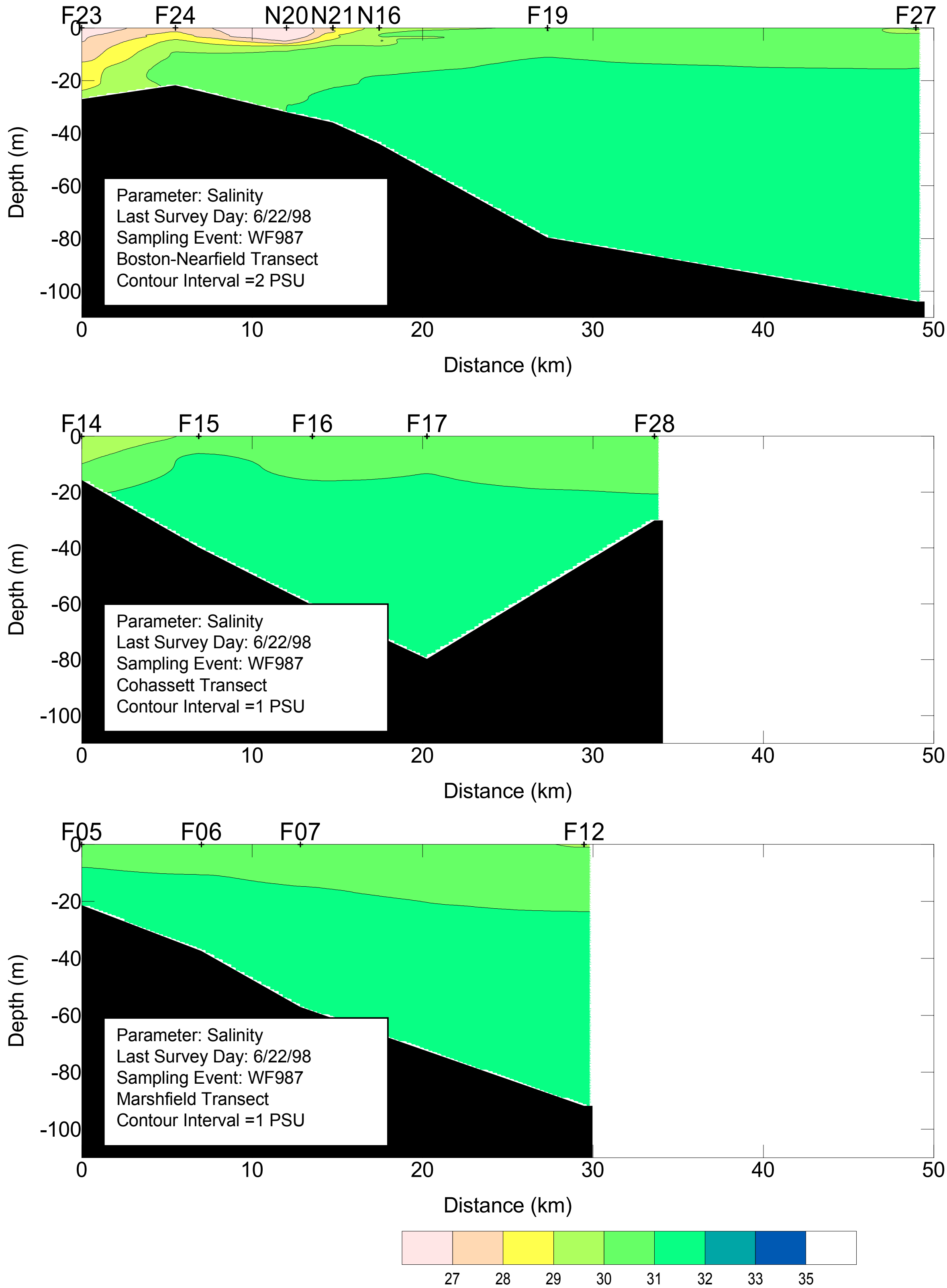


Figure 4-15. Salinity Vertical Transect for Farfield Survey WF987 (Jun 98)

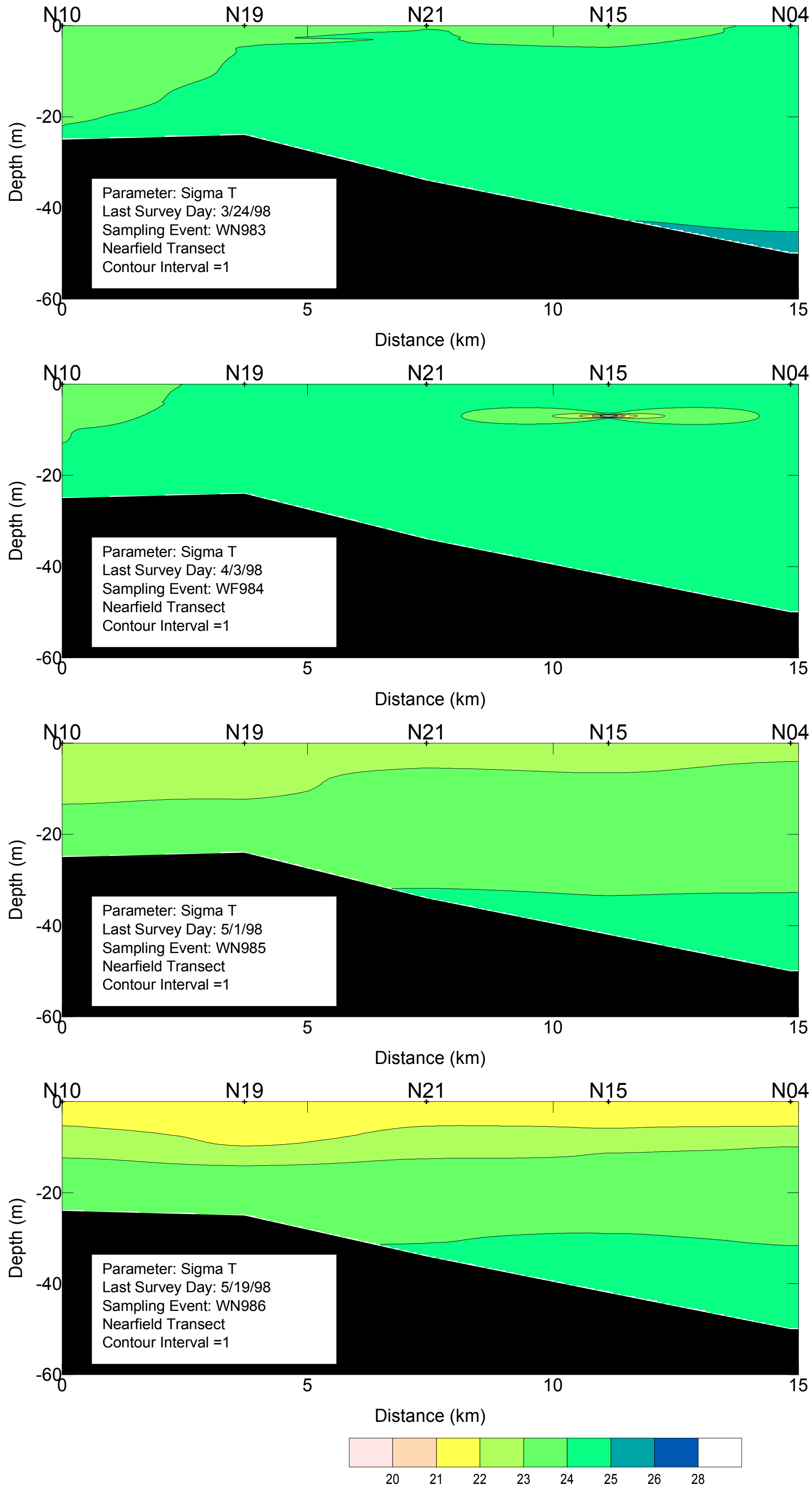


Figure 4-16. Sigma-T Vertical Nearfield Transects for Survey WN983, WF984, WN985 and WN986

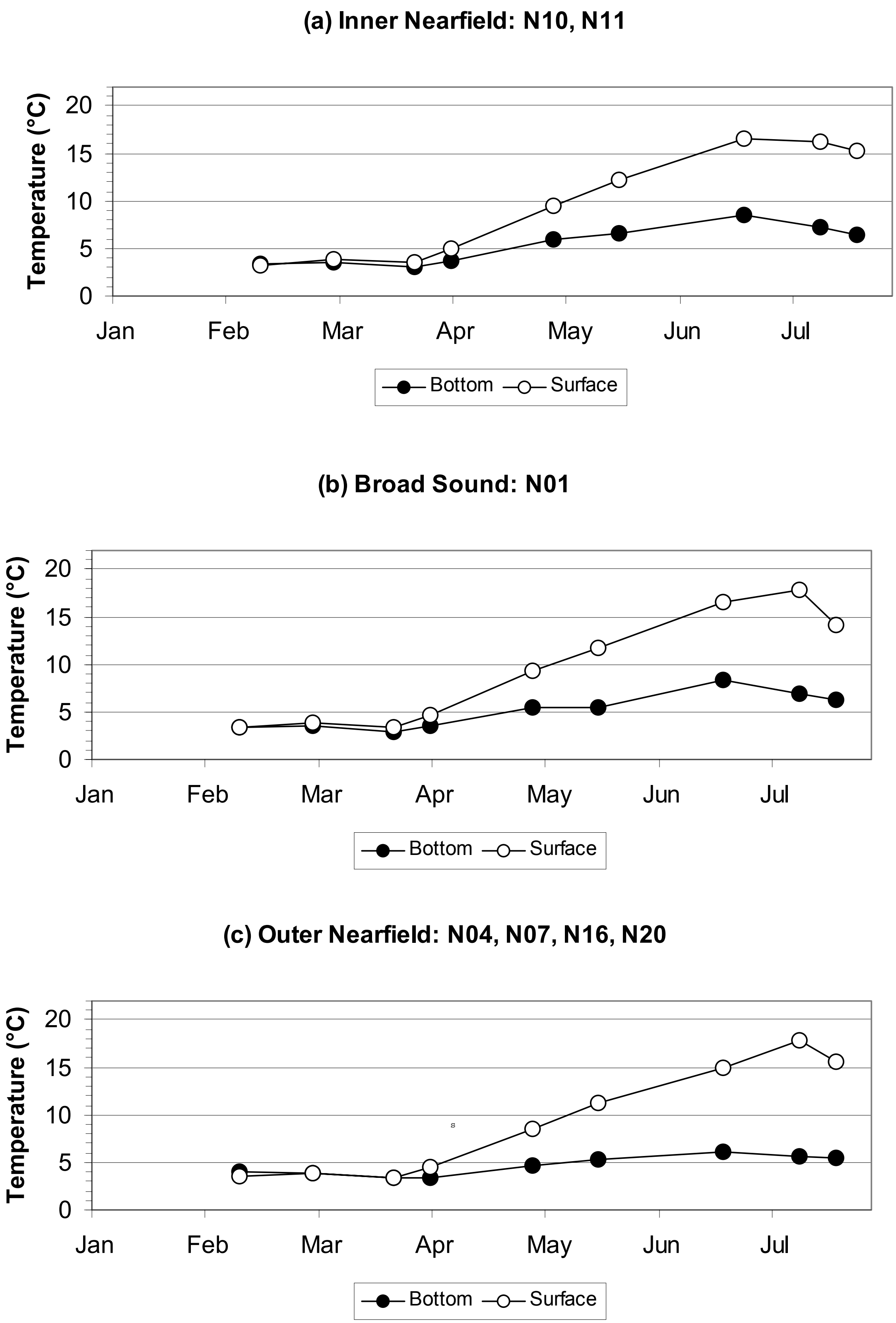


Figure 4-17. Time-Series of Average Surface and Bottom Temperature (°C) in the Nearfield

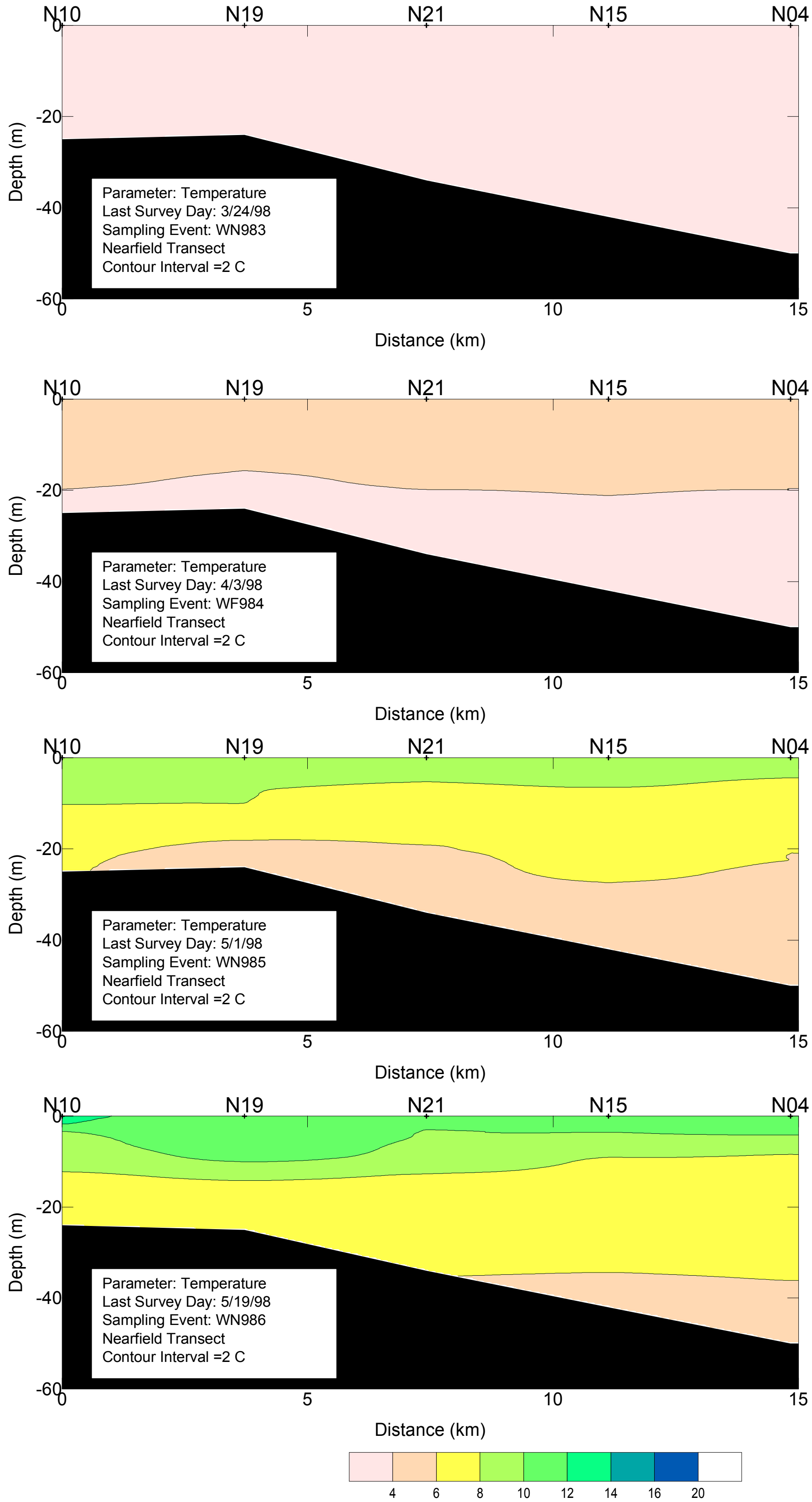
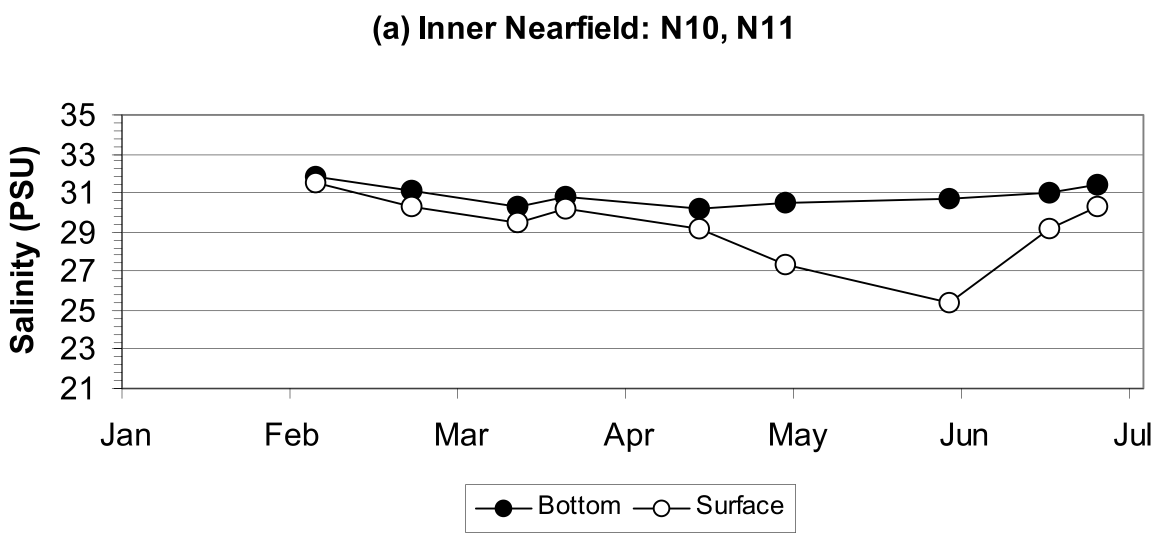
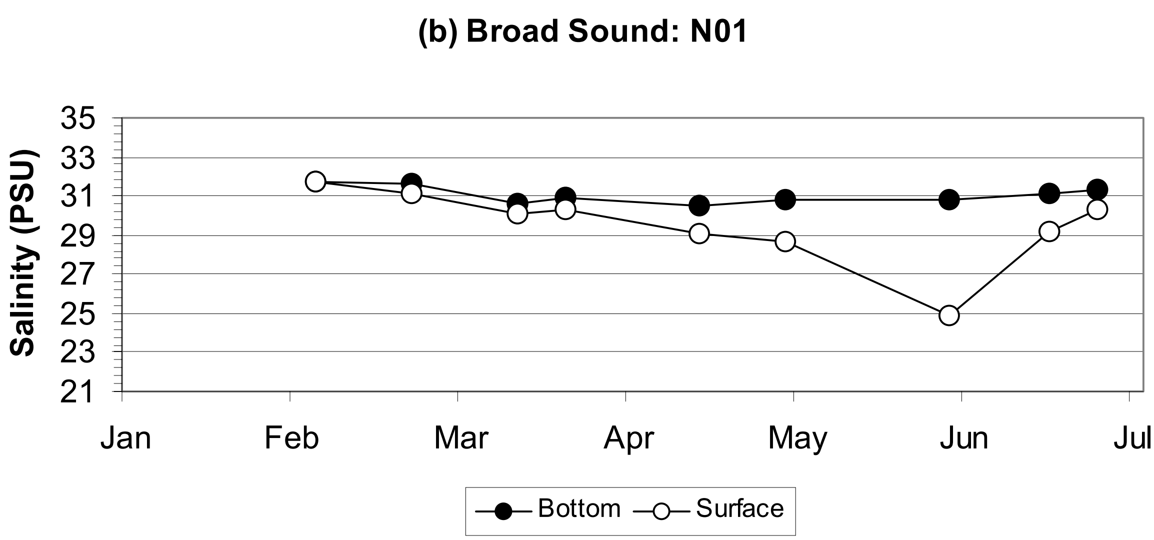


Figure 4-18. Temperature Vertical Nearfield Transects for Survey WN983, WF984, WN985 and WN986





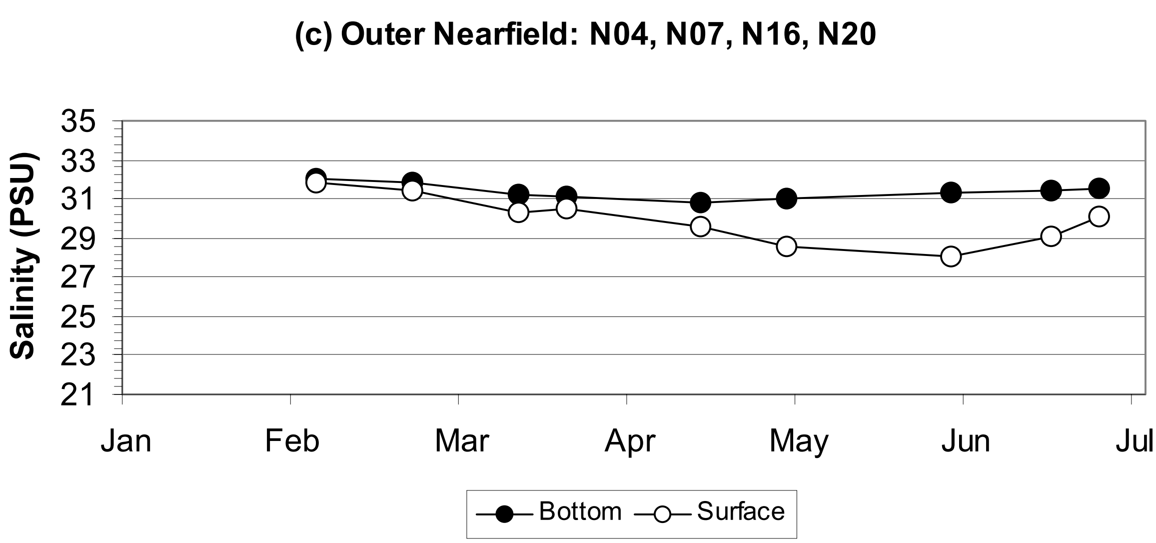


Figure 4-19. Time-Series Plots of Average Surface and Bottom Salinity in the Nearfield

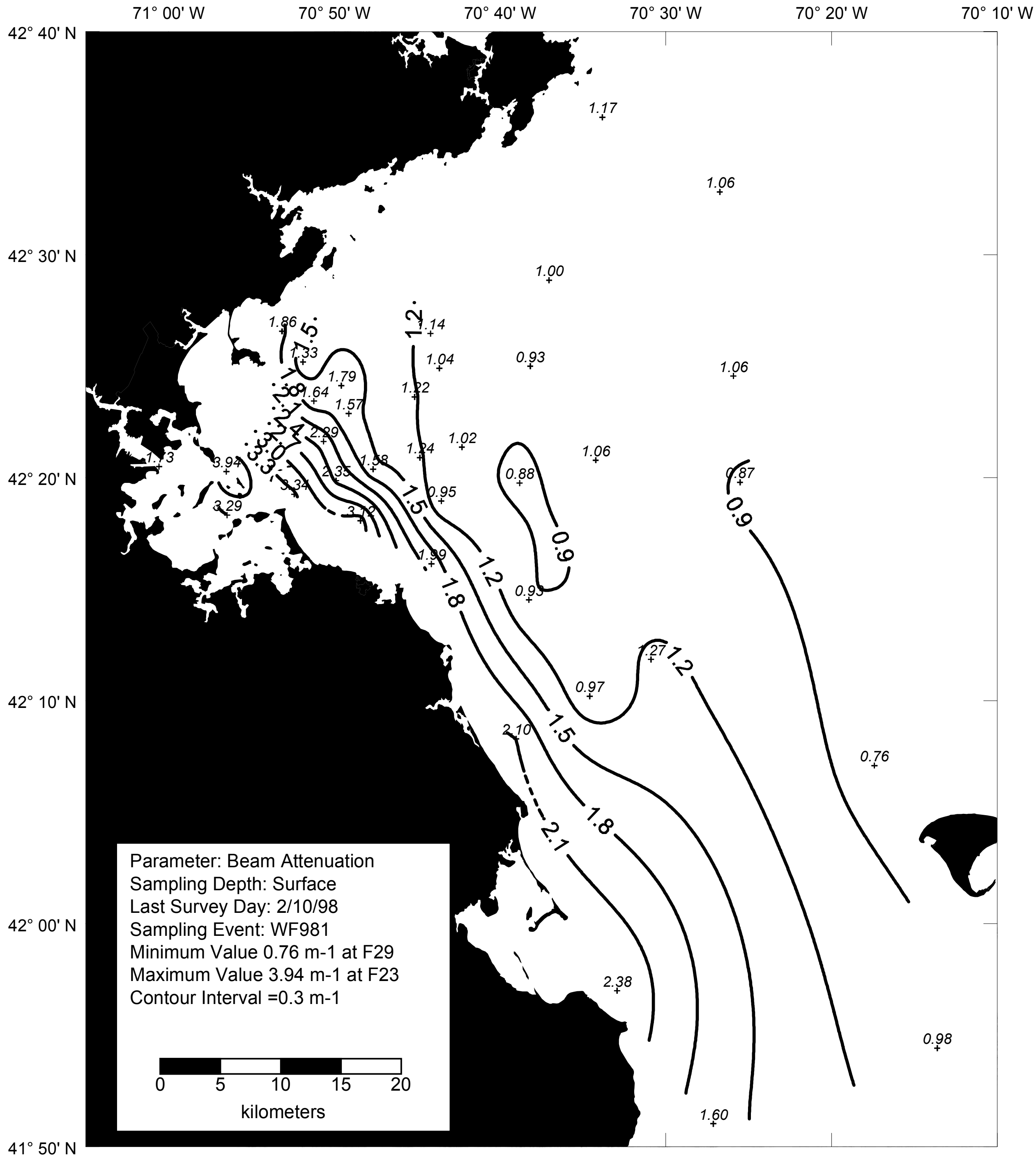


Figure 4-20. Beam Attenuation Surface Contour Plot for Farfield Survey WF981 (Feb 98)

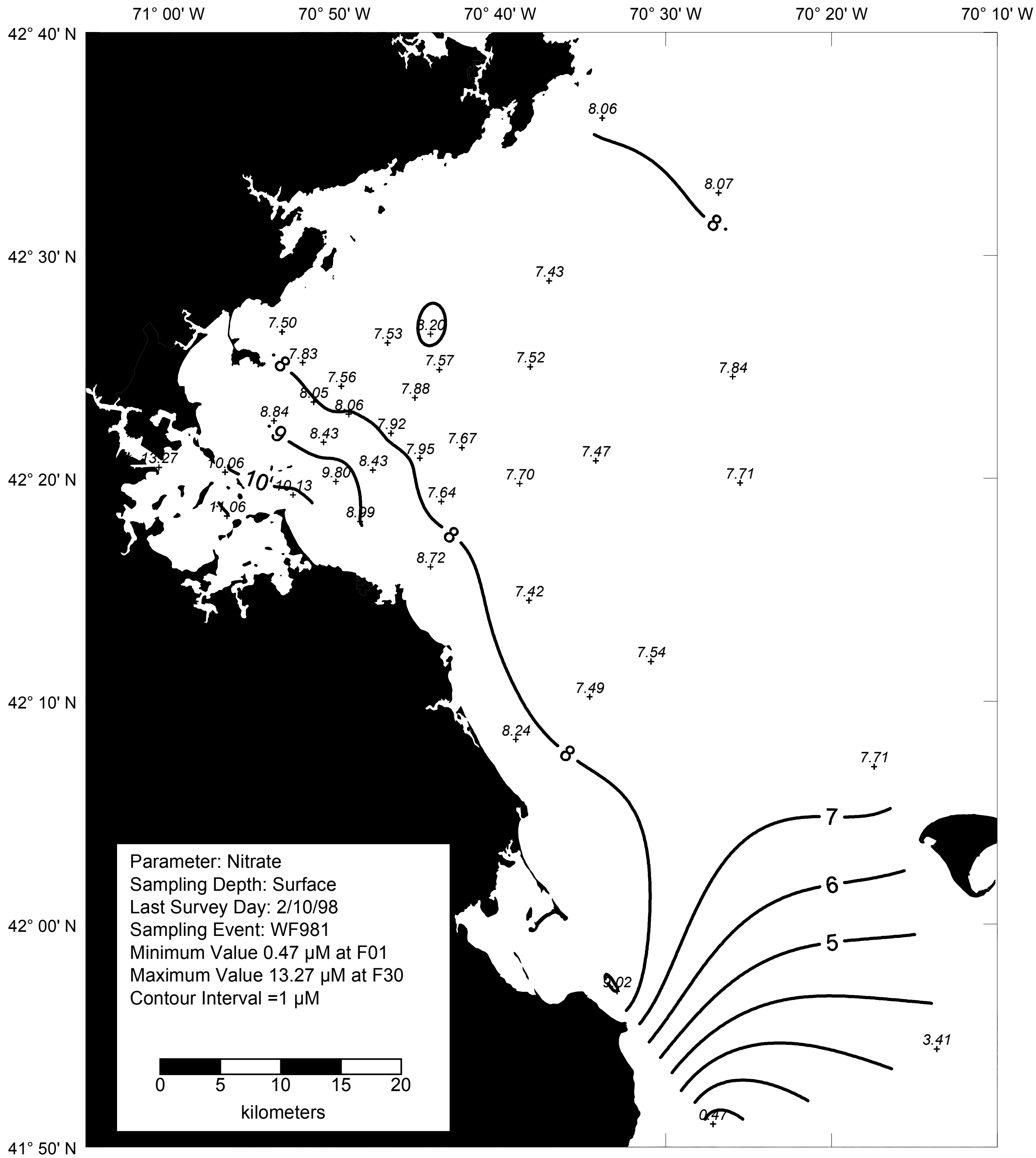


Figure 4-21. Nitrate Surface Contour Plot for Farfield Survey WF981 (Feb 98)

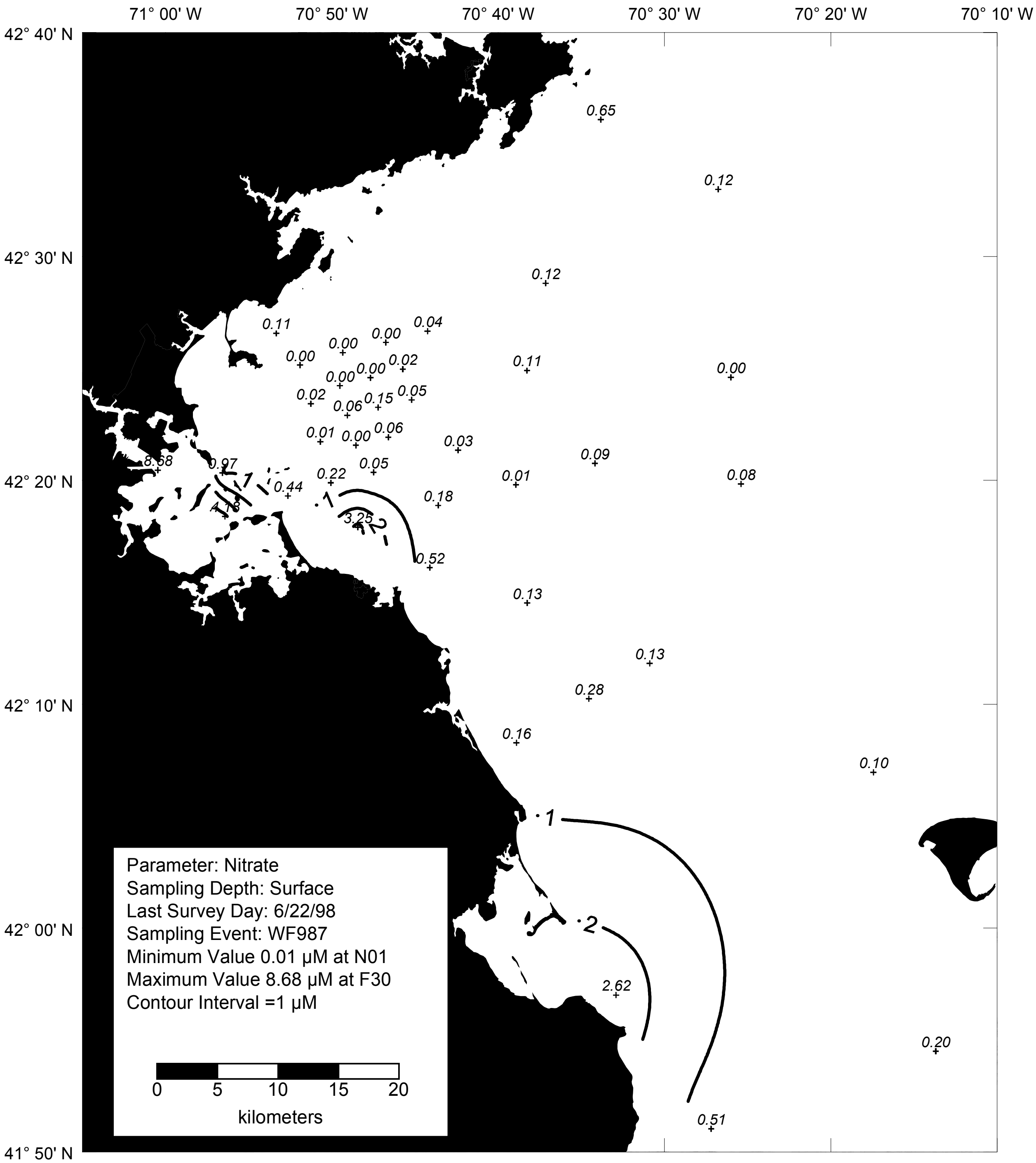


Figure 4-22. Nitrate Surface Contour Plot for Farfield Survey WF987 (Jun 98)

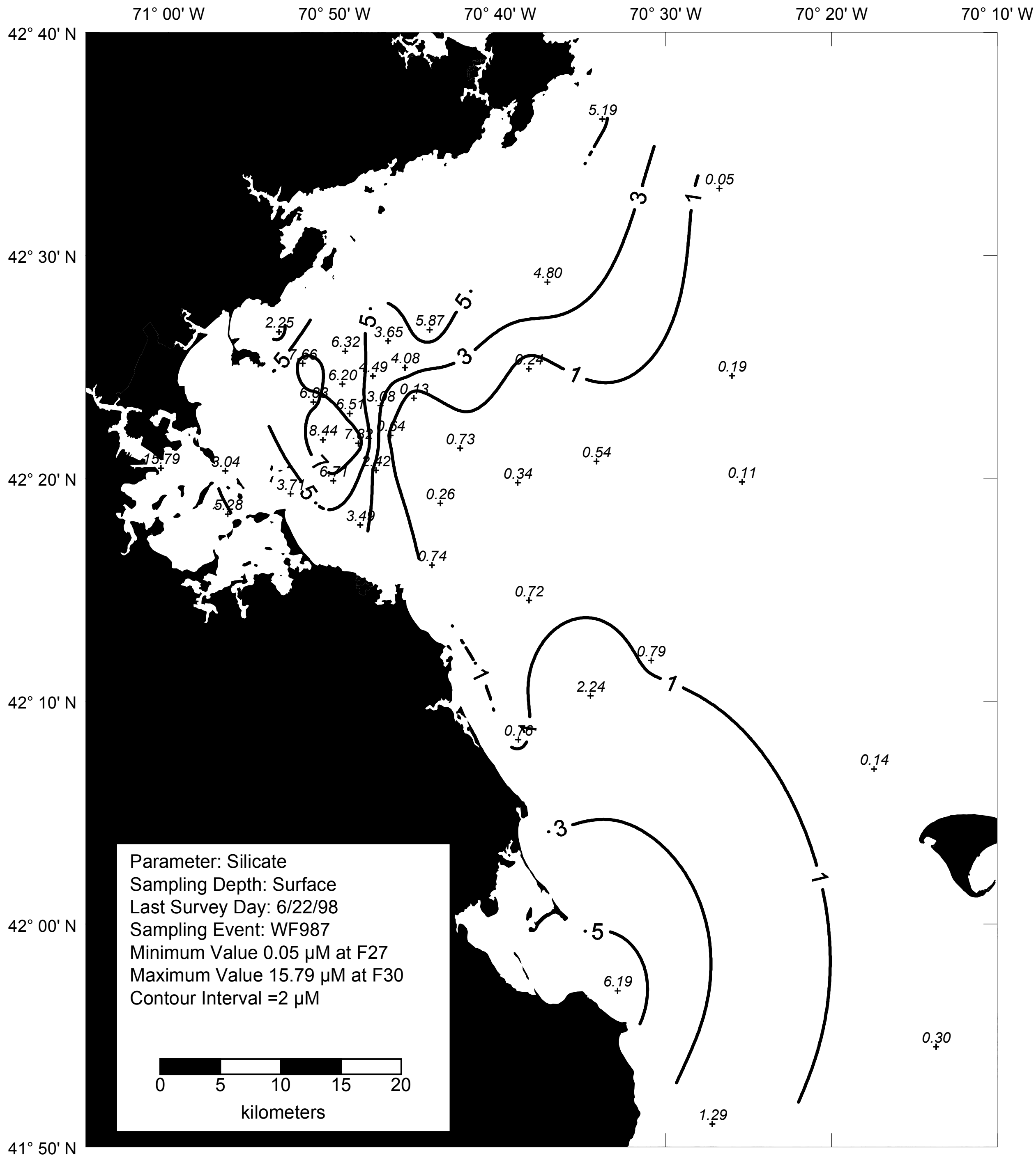


Figure 4-23. Silicate Surface Contour Plot for Farfield Survey WF987 (Jun 98)

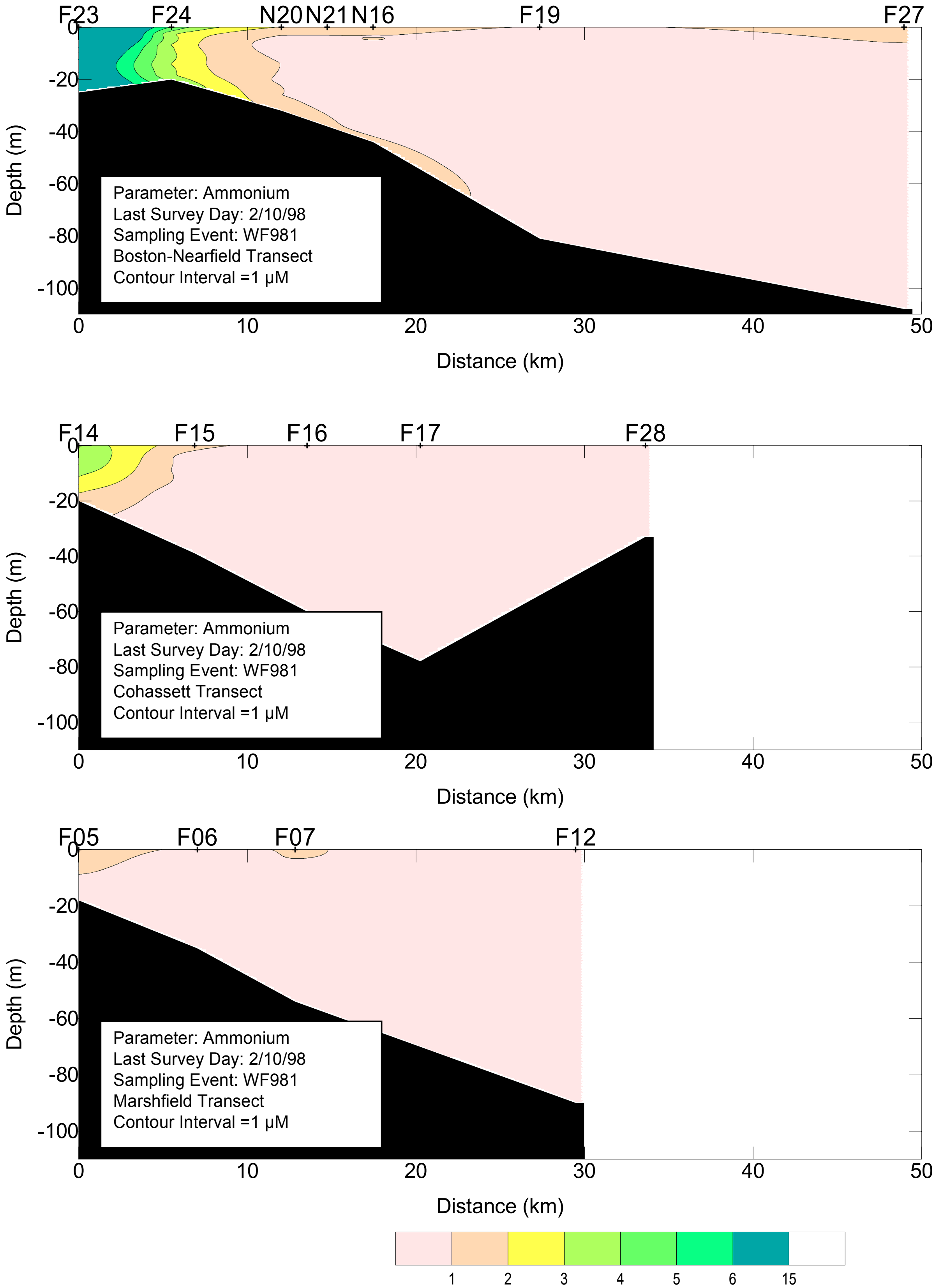


Figure 4-24. Ammonium Vertical Transect Plots for Farfield Survey WF981 (Feb 98)

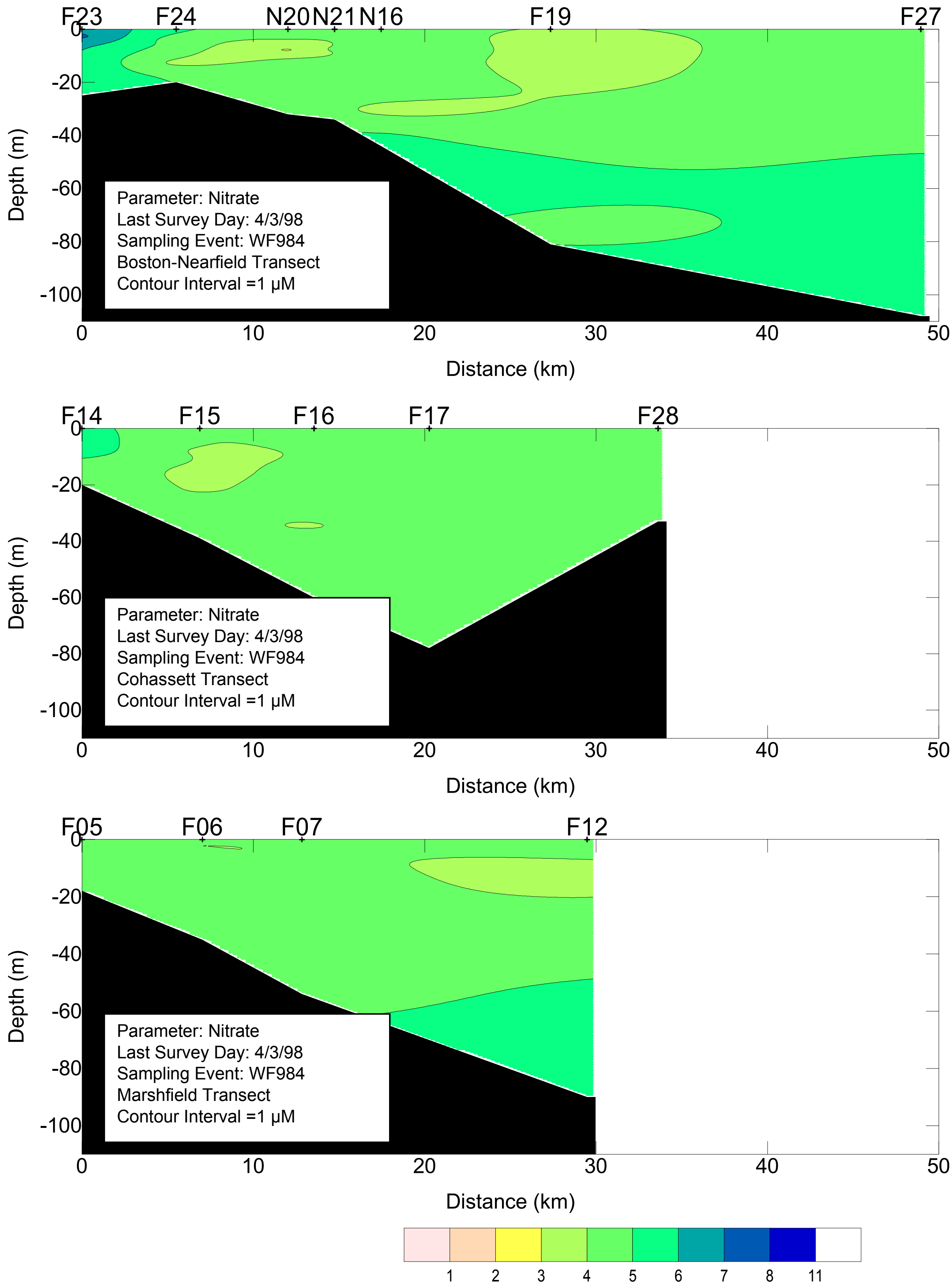


Figure 4-25. Nitrate Vertical Transect Plots for Farfield Survey WF984 (Apr 98)

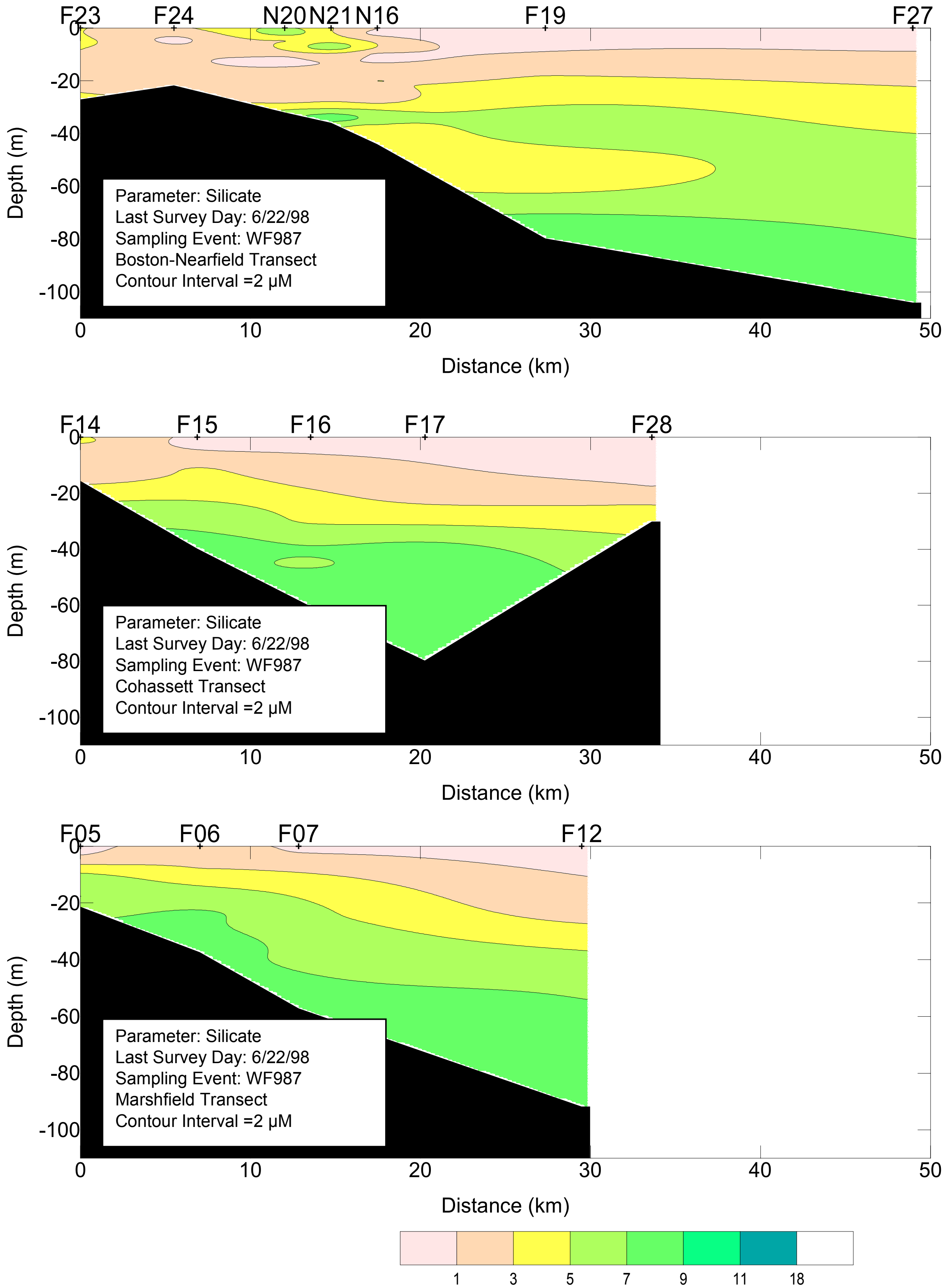
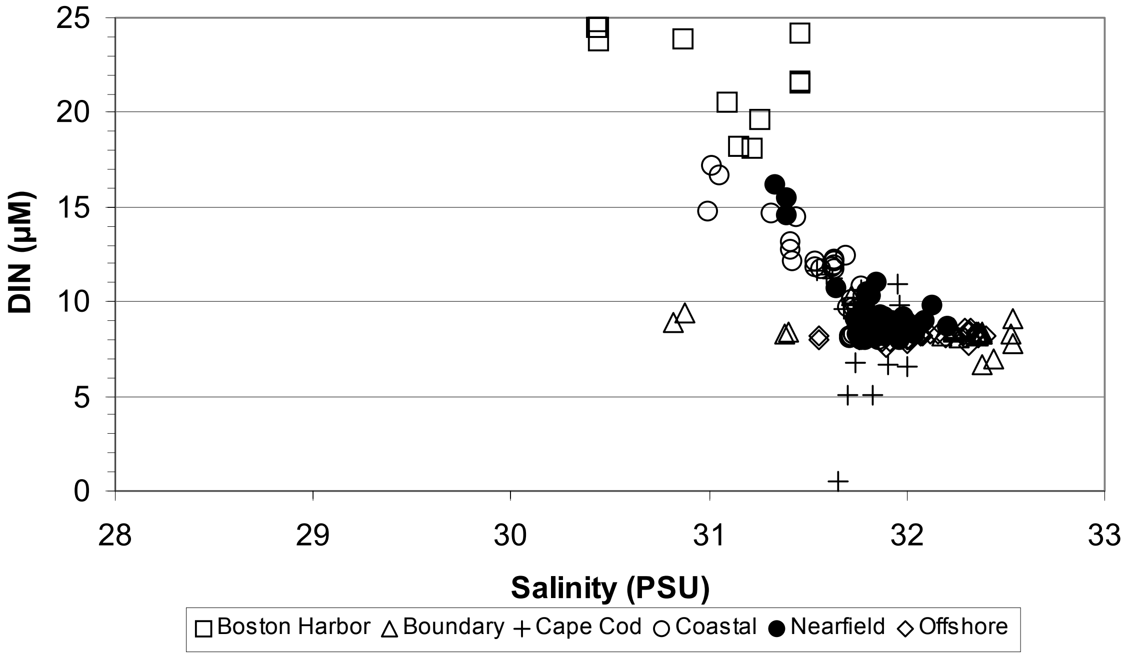


Figure 4-26. Silicate Vertical Transect Plots for Farfield Survey WF987 (Jun 98)

(a) WF981



(b) WF984

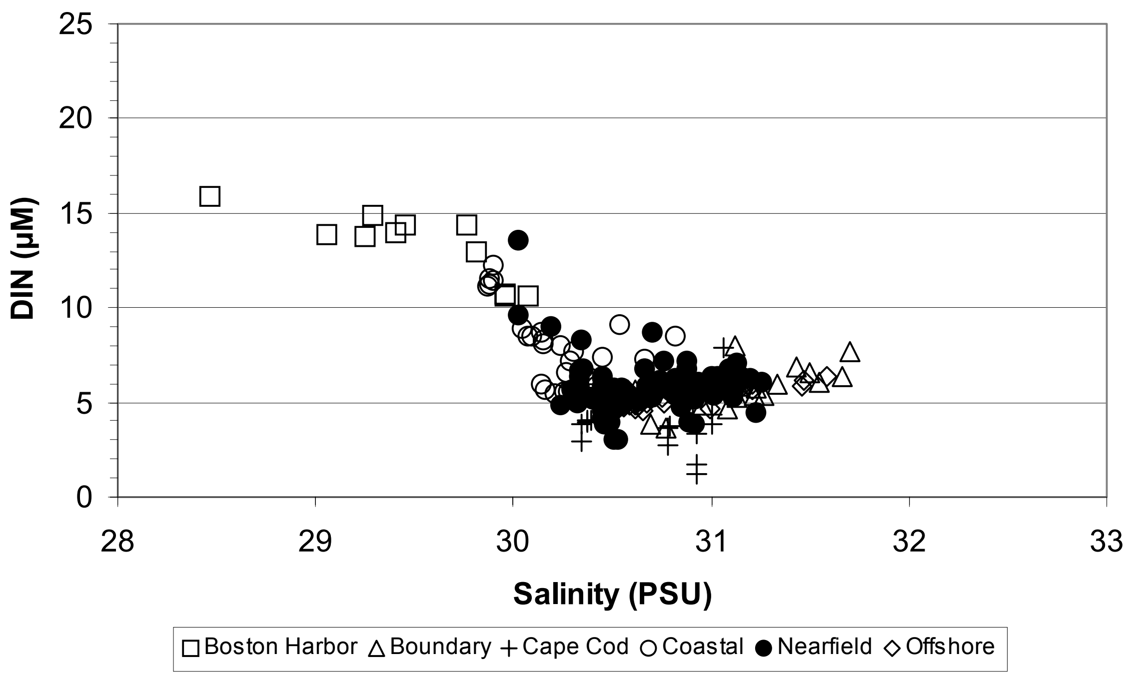


Figure 4-27. DIN vs. Salinity for All Depths During Three Farfield Surveys (WF981, WF984, and WF987)

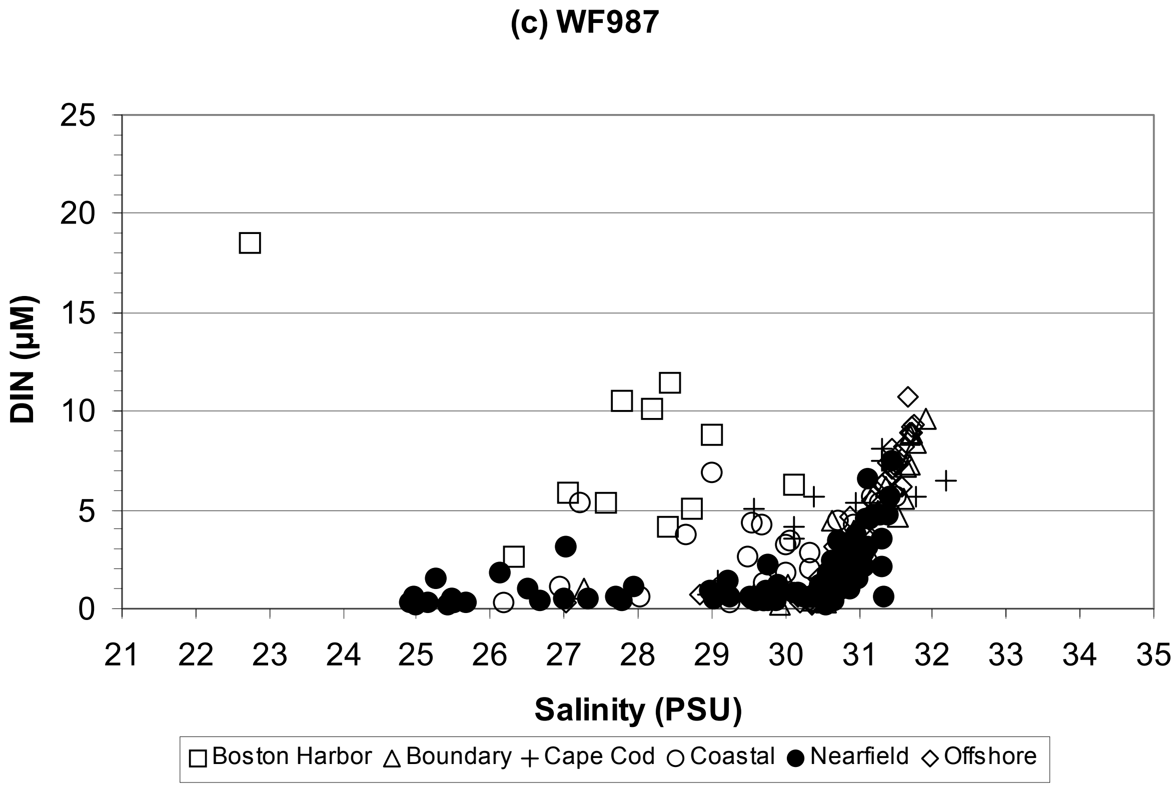


Figure 4-27 (Cont.). DIN vs. Salinity for All Depths During Three Farfield Surveys (WF981, WF984, and WF987)

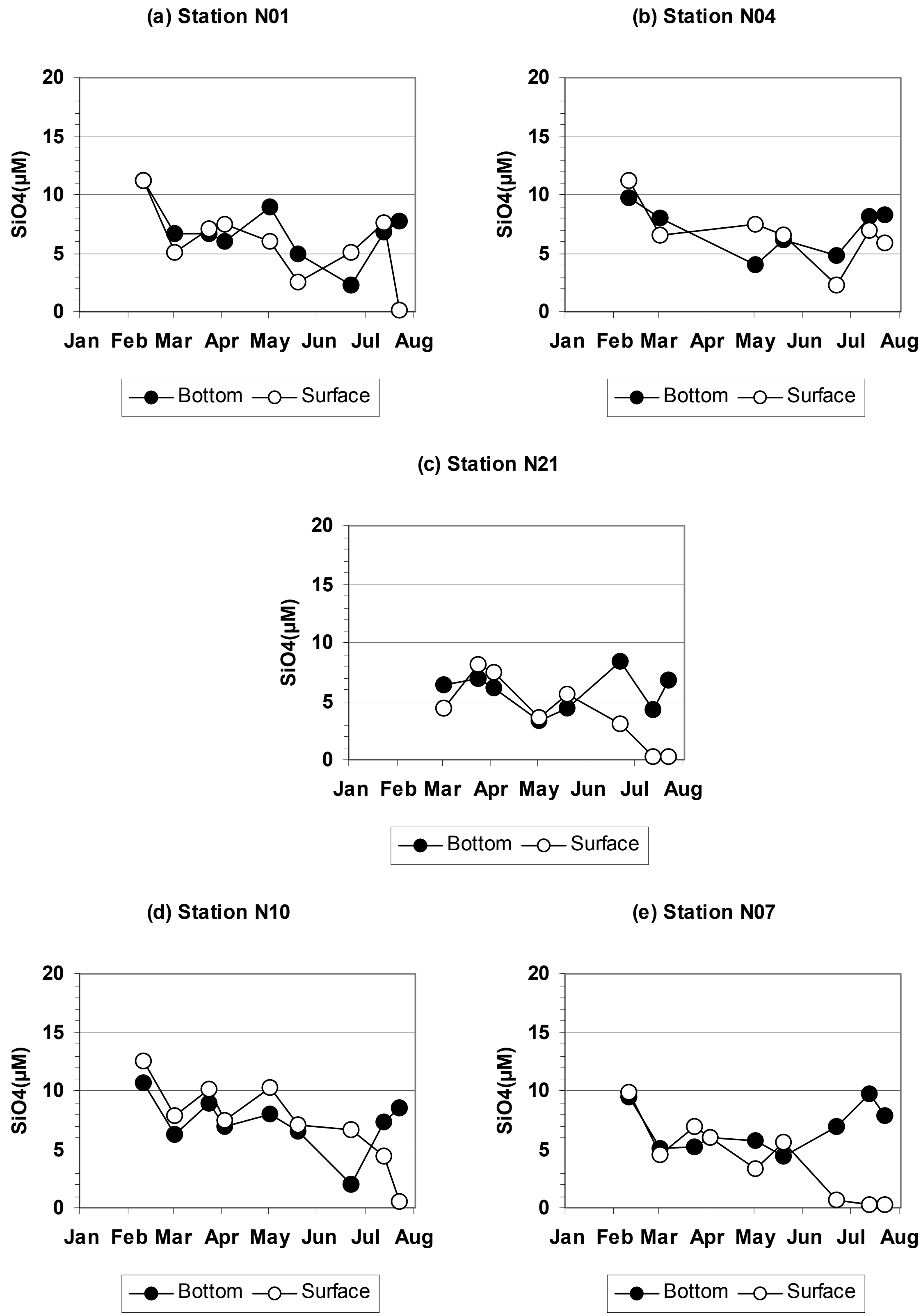


Figure 4-28. Time-Series of Surface and Bottom Water Silicate Concentration in Five Nearfield Stations Note: The arrangement of the figures on this page mimic the relative positions of the stations.

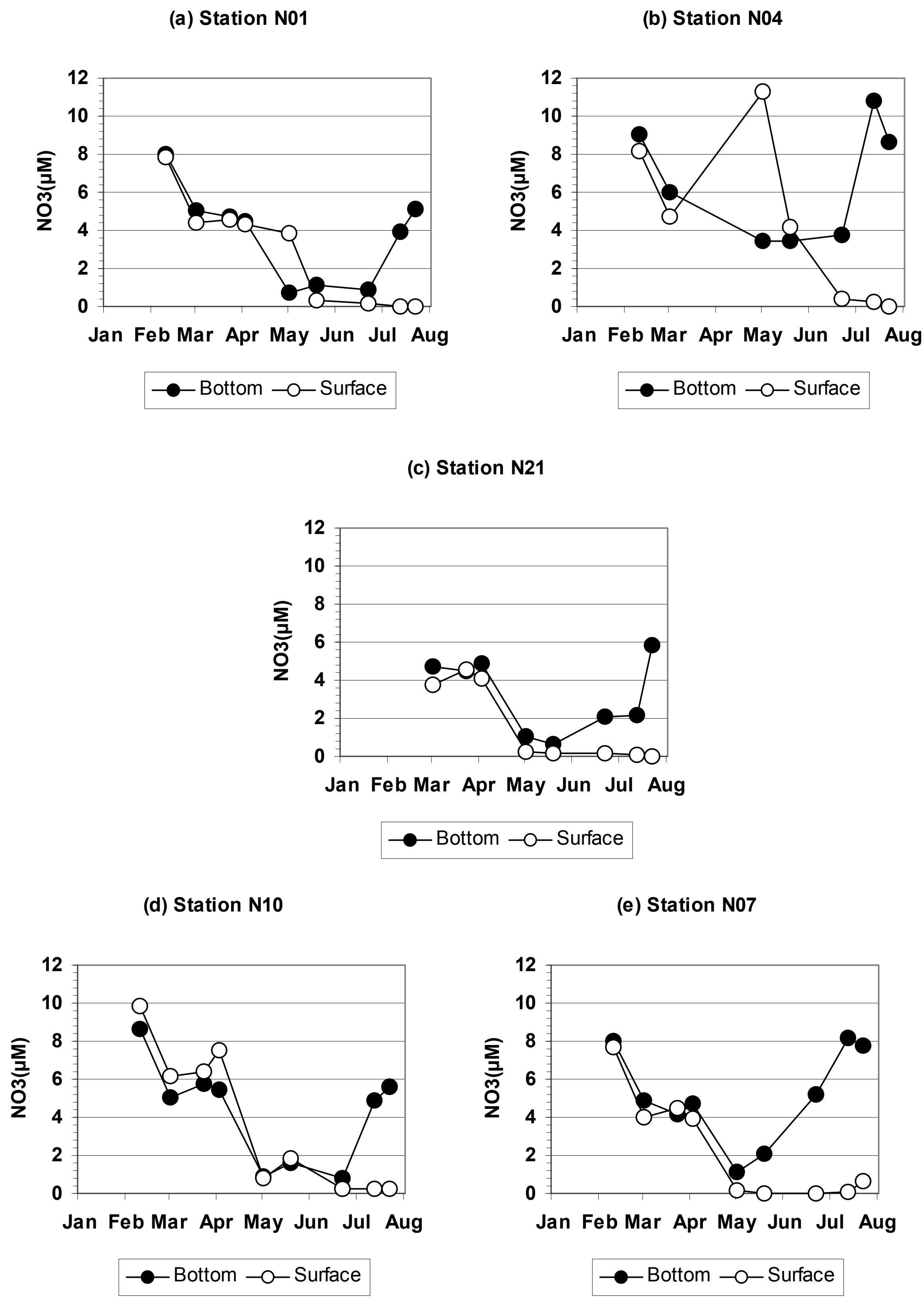


Figure 4-29. Time-Series of Surface and Bottom Water Nitrate Concentration in Five Nearfield Stations

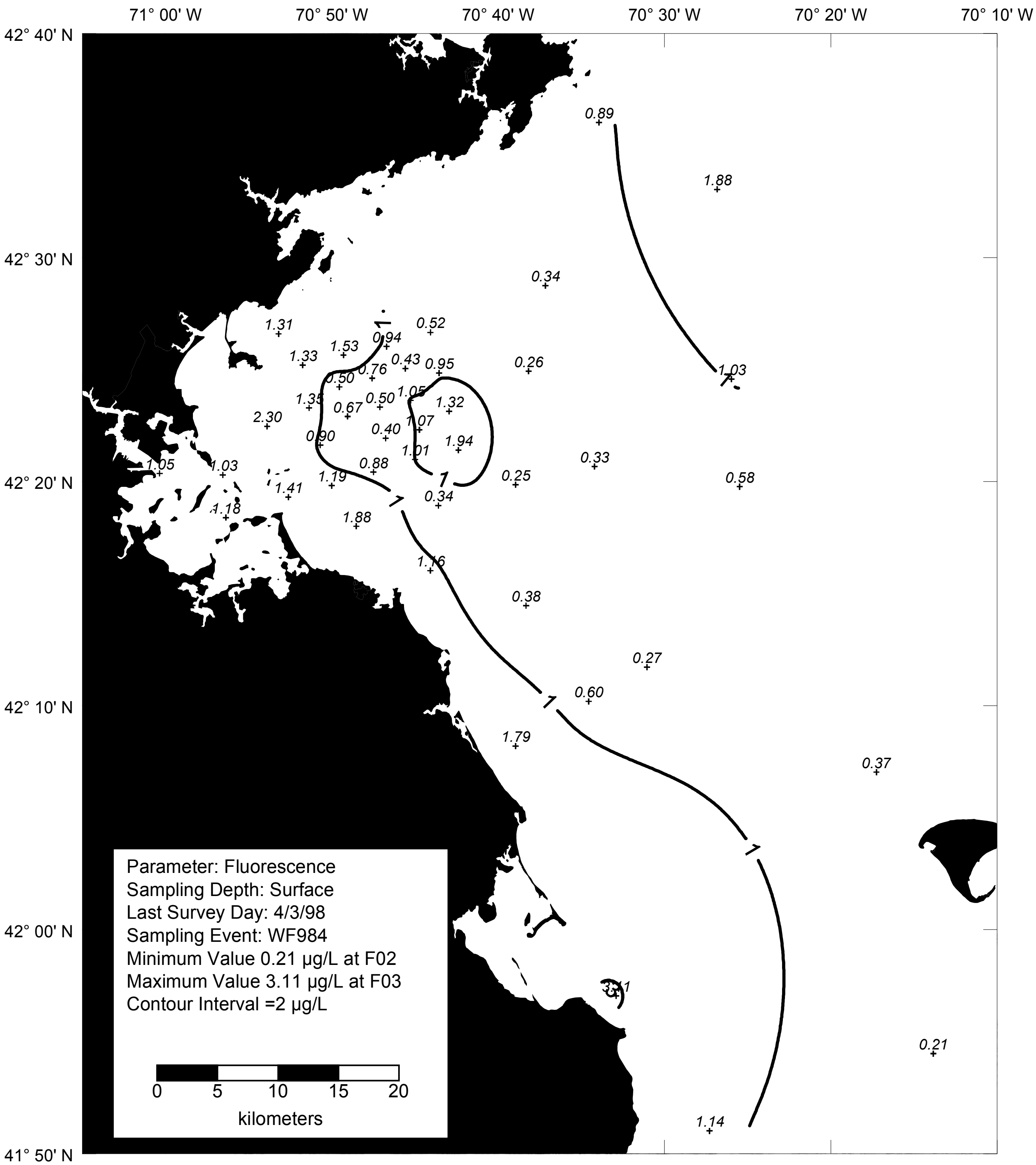


Figure 4-30. Fluorescence Surface Contour Plot for Farfield Survey WF984 (Apr 98)

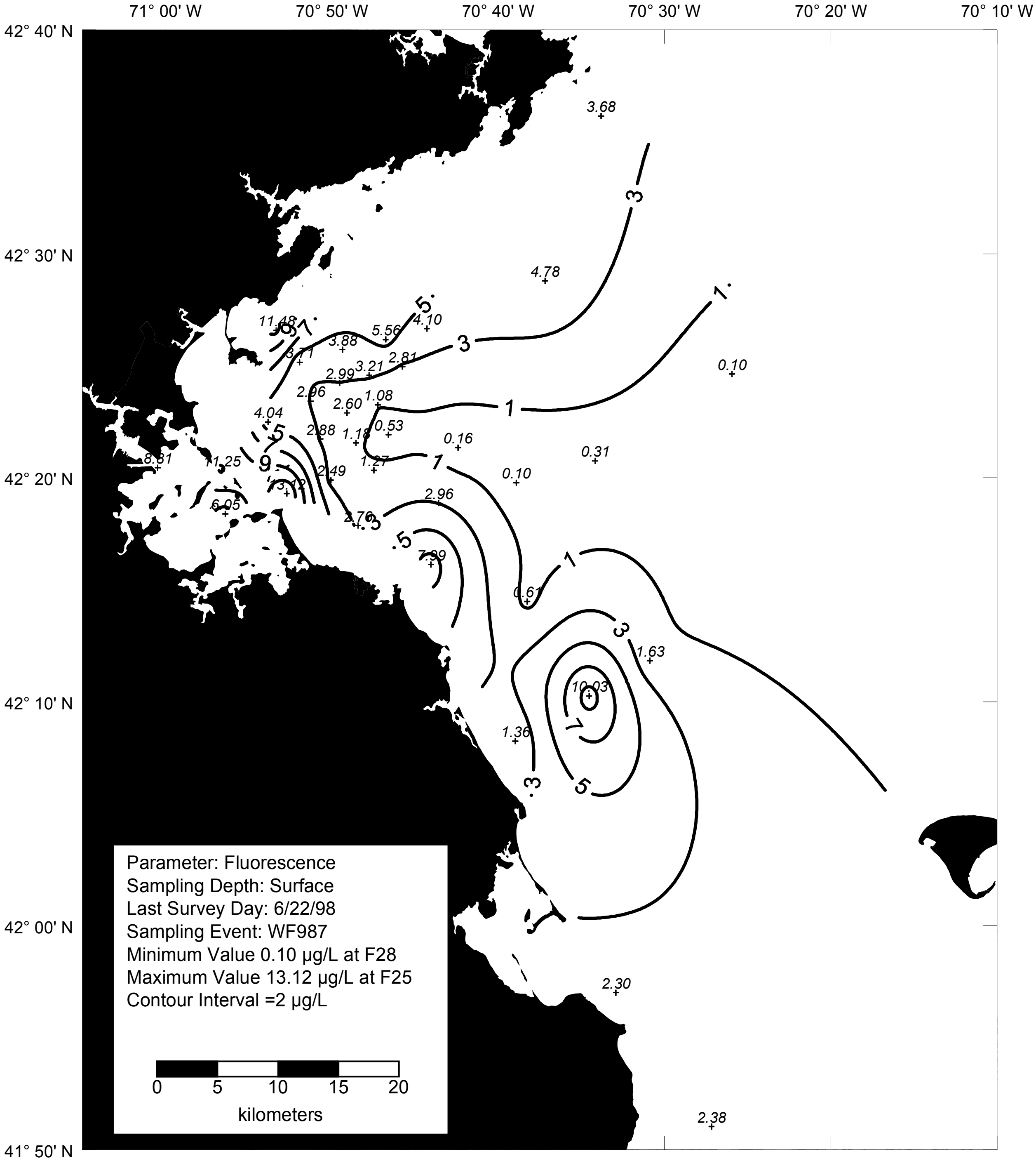


Figure 4-31. Fluorescence Surface Contour Plot for Farfield Survey WF987 (Jun 98)

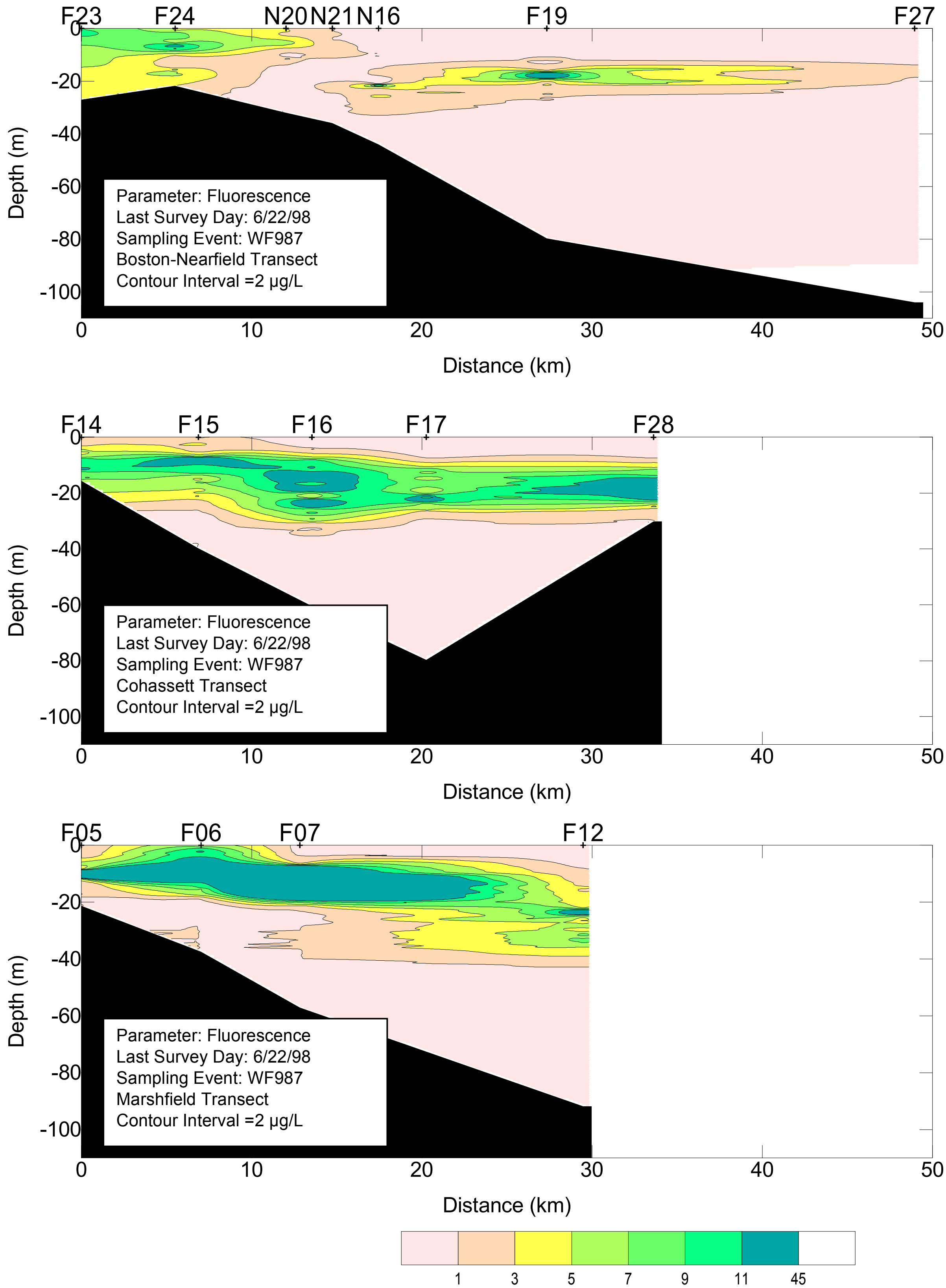


Figure 4-32. Fluorescence Vertical Transect Plots for Farfield Survey WF987 (Jun 98)

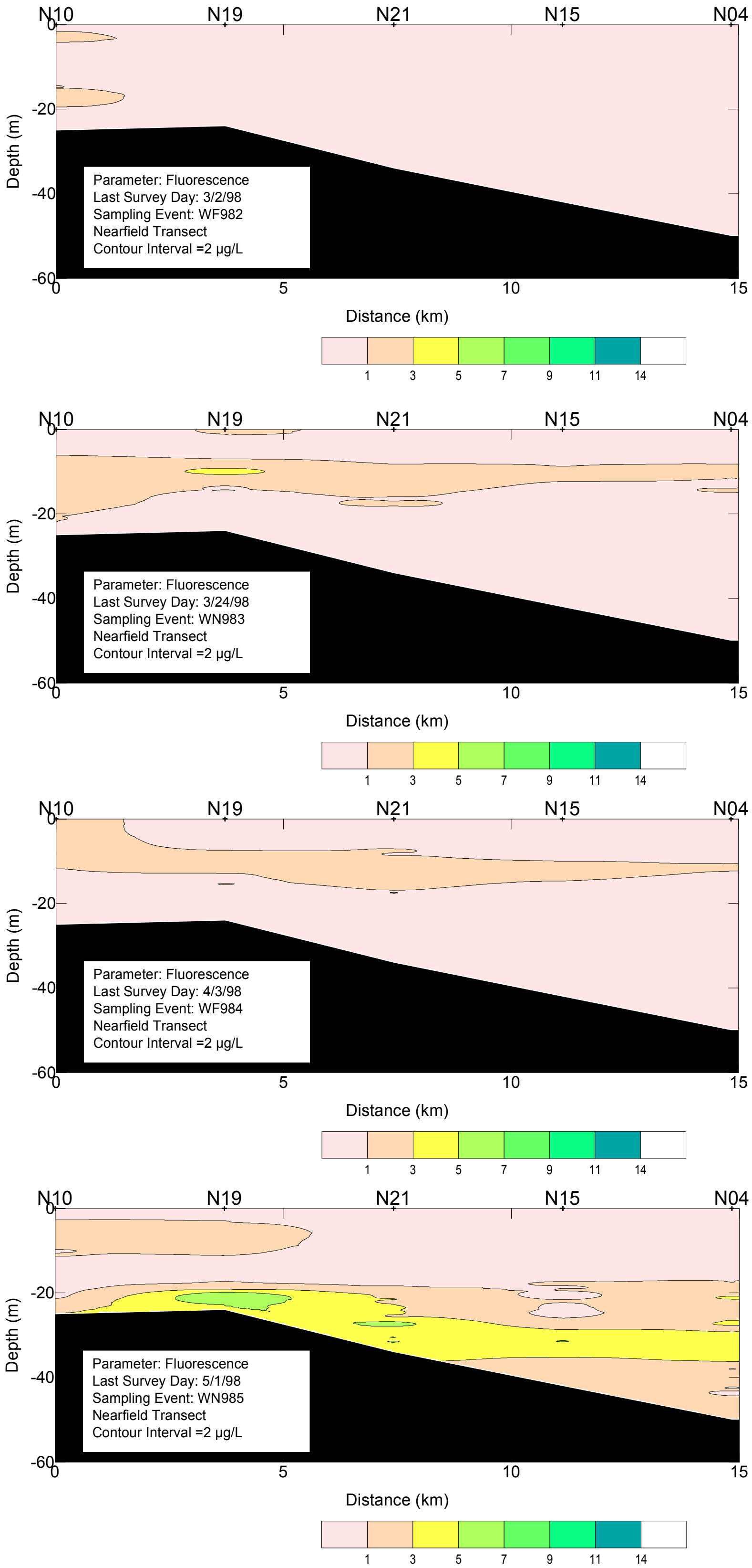


Figure 4-33. Fluorescence Vertical Nearfield Transect Plots for Surveys WF982 through WN985

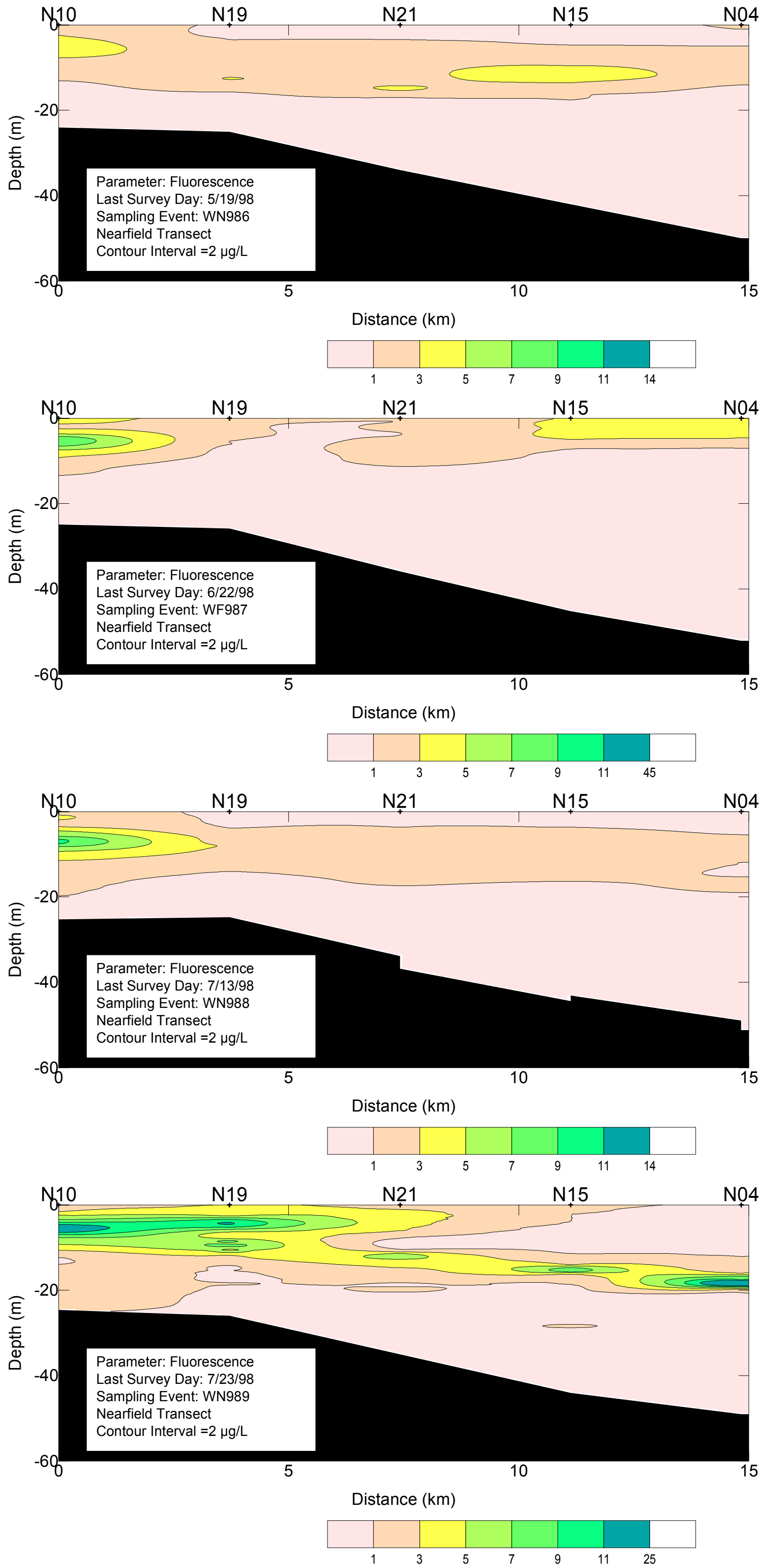
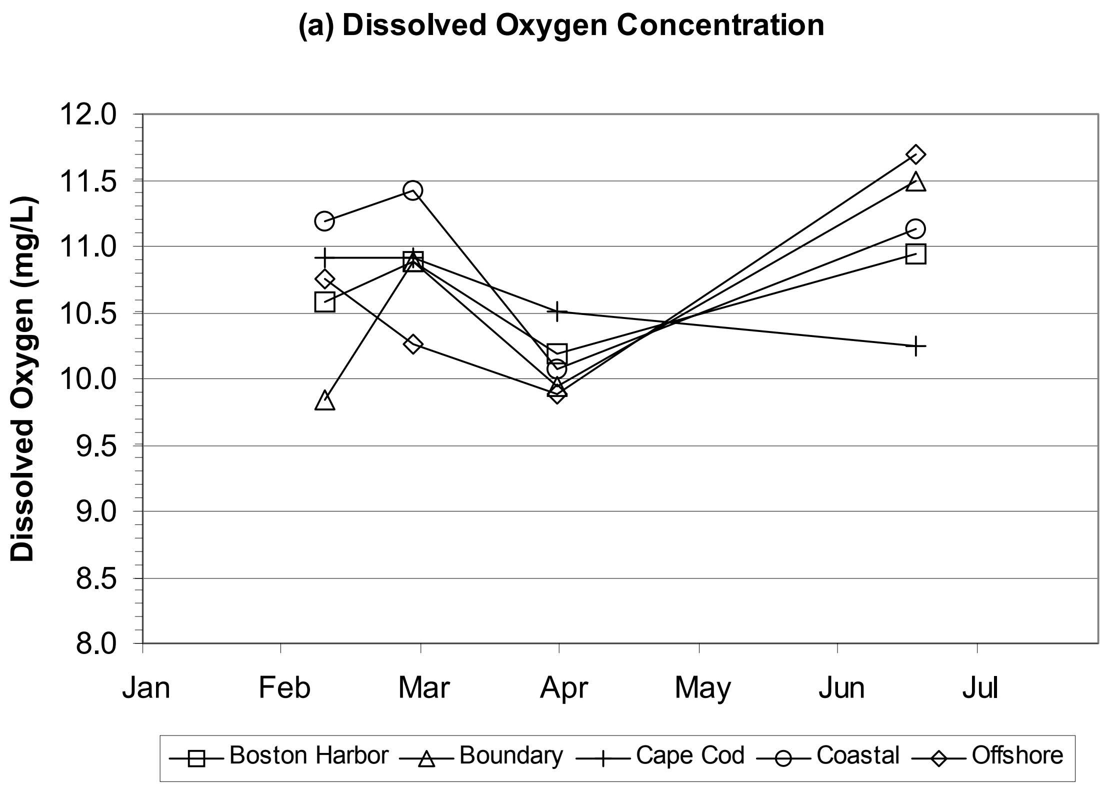


Figure 4-34. Fluorescence Vertical Nearfield Transect Plots for Surveys WN986 through WN989



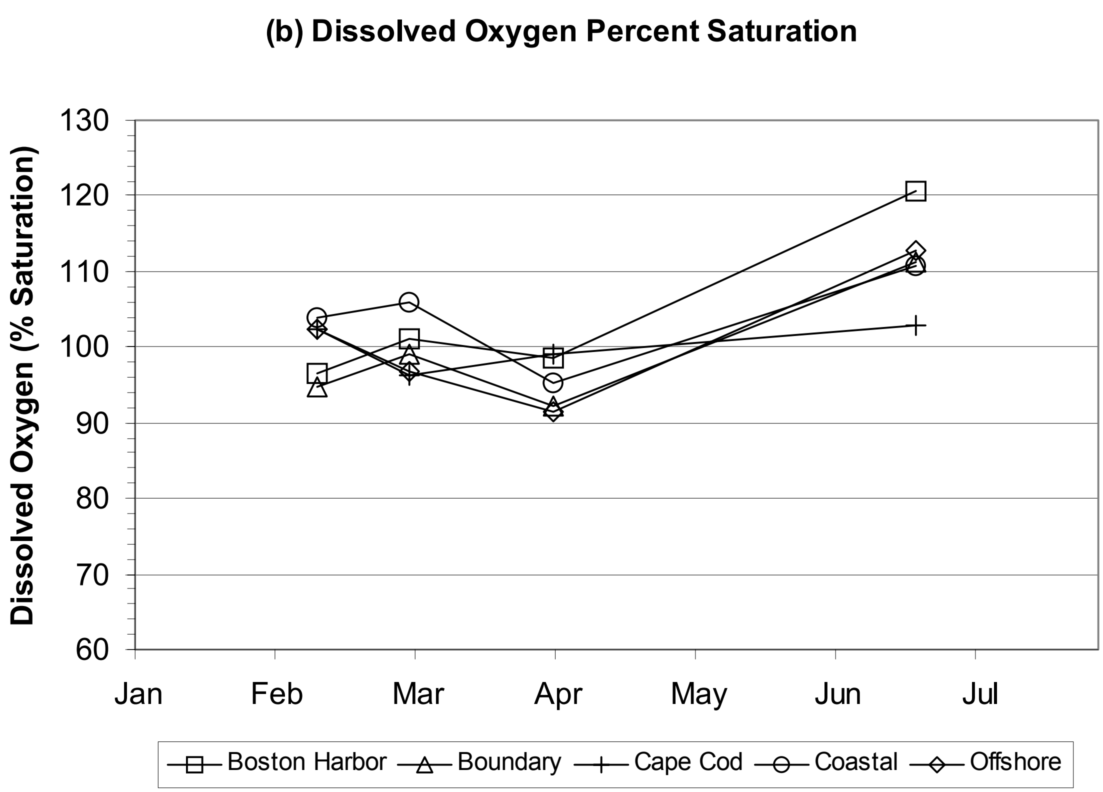


Figure 4-35. Time Series of Bottom Water Average DO Concentration and Percentage Saturation in the Farfield

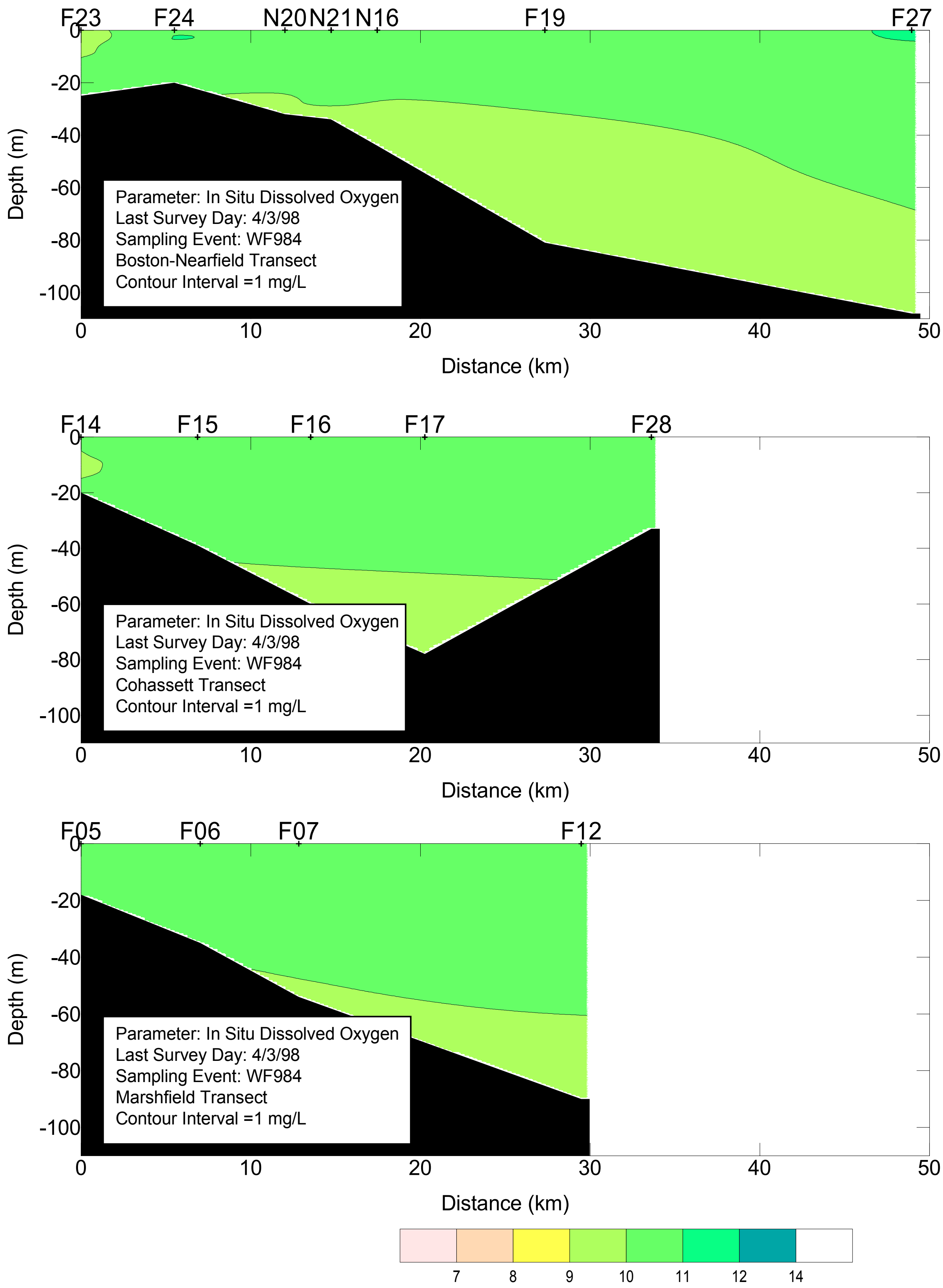


Figure 4-36. Dissolved Oxygen Vertical Transects for Survey WF984 (Apr 98)

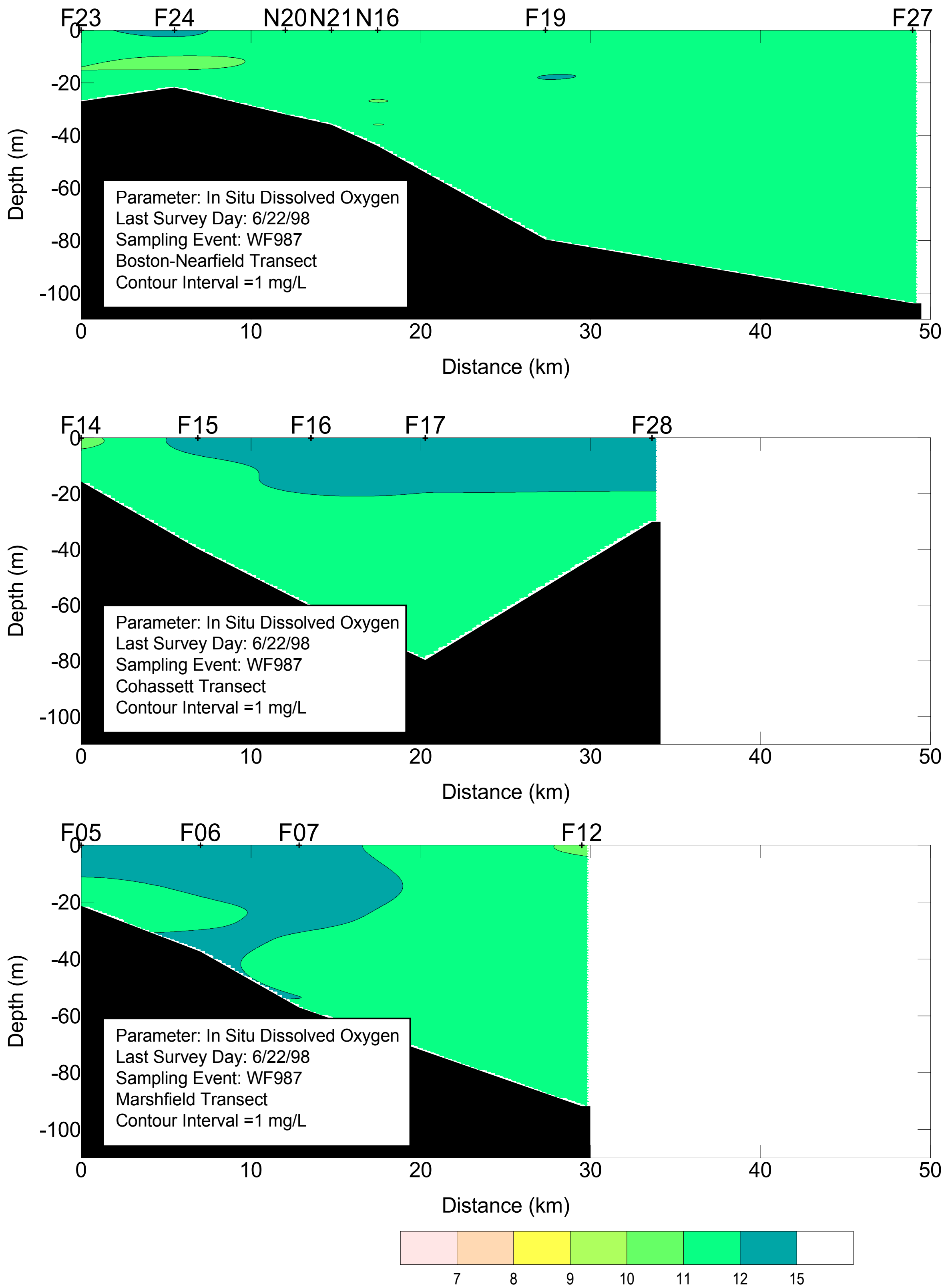
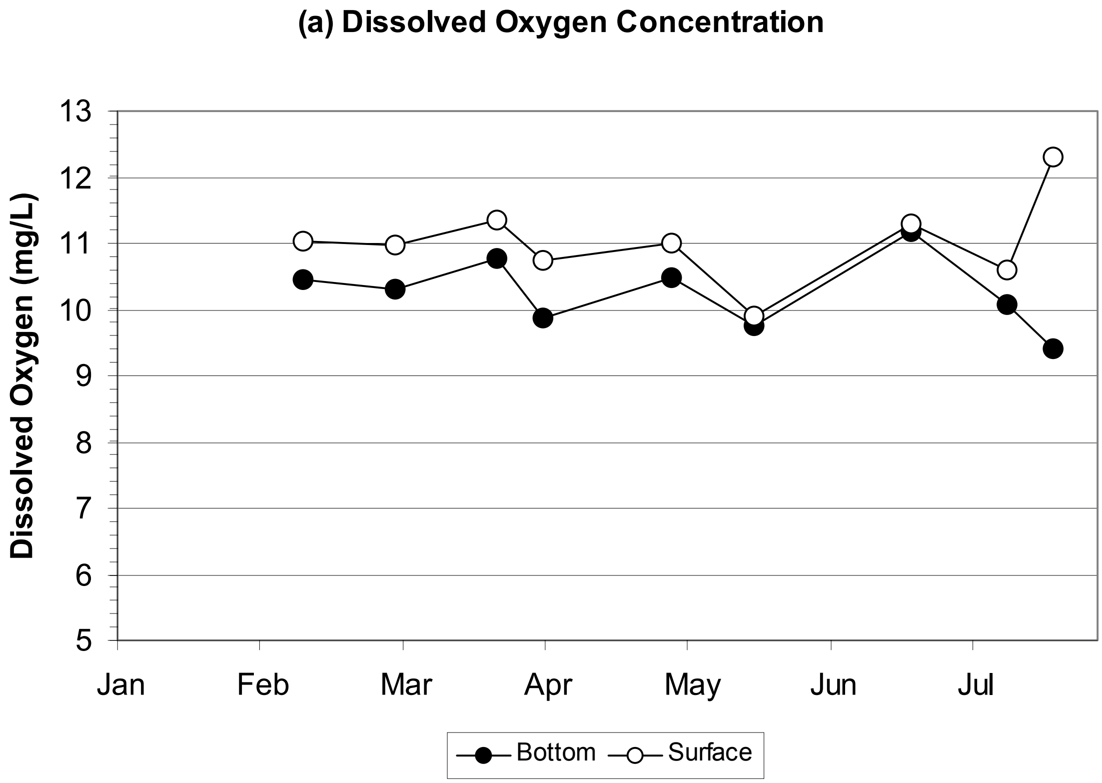


Figure 4-37. Dissolved Oxygen Vertical Transects for Survey WF987 (Jun 98)



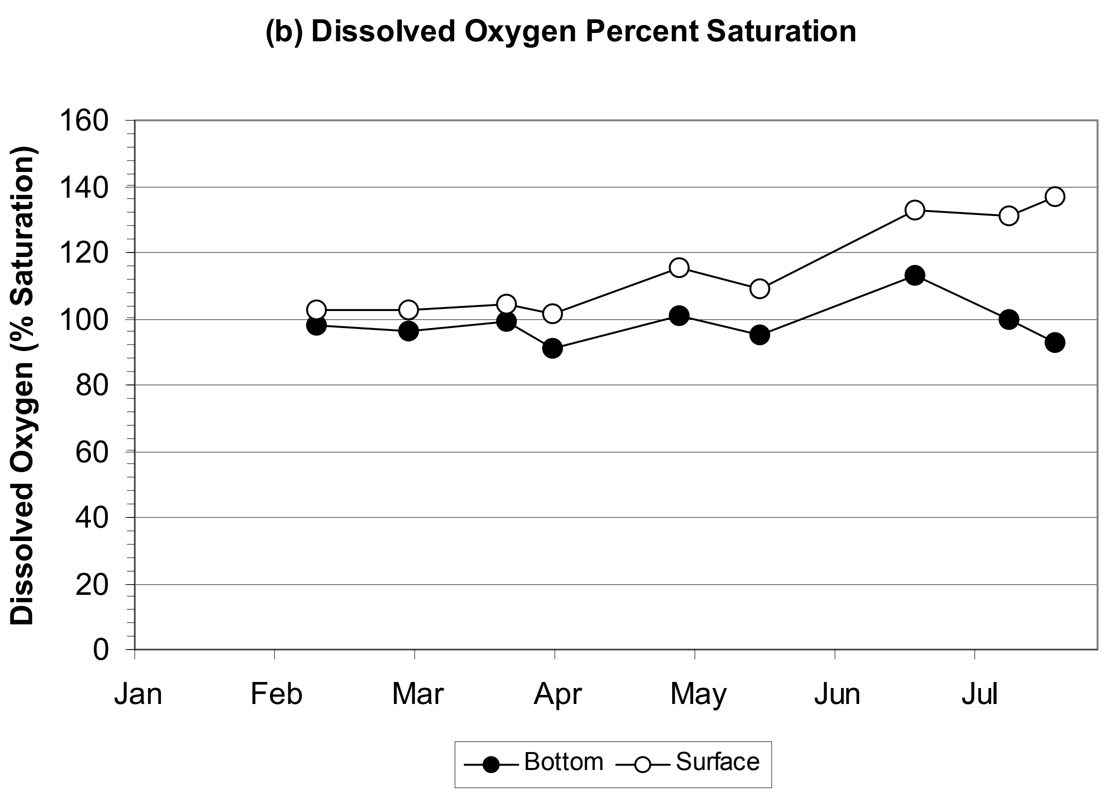


Figure 4-38. Time Series of Bottom and Surface Average DO Concentration and Percentage Saturation in the Nearfield

5.0 PRODUCTIVITY, RESPIRATION, AND PLANKTON RESULTS

5.1 Productivity

Production measurements were taken at two nearfield stations (N04, N18) and one farfield station (F23) near the entrance of Boston Harbor. All three stations were sampled on February 9, 1998 (WF981), April 2, 1998 (WF984), and June 22, 1998 (WF987). Stations N04 and N18 were additionally sampled on March 23, (WN983), May 1, (WN985), May 19, 1998 (WN986), July 8, 1998 (WN988), and July 23, 1998 (WN989). The measurements for March 1, 1998 (WF982) were lost when the incubators failed. Production values for WF982 (stations N04, N18 and F23) were estimated using the model parameters from the first cruise (WF981) and the *in situ* data for temperature, irradiance, and light attenuation from the second. The major assumption of this approach is that model parameters remained constant over the 3-wk period between cruises, a relatively good assumption given the similar and very low chlorophyll values for both cruises. With the exception of WF982, samples were collected at five depths throughout the euphotic zone. Production was determined by measuring ^{14}C at varying light intensities as summarized below and in Appendix A.

In addition to samples collected from the water column, productivity calculations also utilized light attenuation data from a CTD-mounted 4π sensor, and incident light time-series data from a 2π irradiance sensor located on Deer Island, MA. After collection of the productivity samples, they were returned to the Marine Ecosystems Research Laboratory (MERL) in Rhode Island and incubated in temperature controlled incubators. The resulting photosynthesis versus light intensity (P-I) curves (Figure 5-1 and comprehensively in Appendix E) were used, in combination with light attenuation and incident light information, to determine hourly production at 15-min intervals throughout the day for each sampling depth.

For this semi-annual report, areal production (mg C m^{-2} d^{-1}) and chlorophyll-specific areal production (mg C mg Chl^{-1} d^{-1}) are presented (Figures 5-2 and 5-3). Areal productions are determined by integrating measured productivity (and chlorophyll-specific productivity) over the depth interval. Chlorophyll-specific productivity for each depth was first determined by normalizing productivity by measured chlorophyll *a*. Productivity and chlorophyll-specific productivity for each depth are also presented as contour plots (Figures 5-4 and 5-7).

5.1.1 Areal Production

Areal production at the nearfield stations (N04, N18) was less than 300 mg C m^{-2} d^{-1} from February through April (WF981-WF984) then increased in late spring (WN985-WN986) to levels of 300-400 mg C m^{-2} d^{-1} (Figure 5-2). Maximum productivity between the nearfield stations (>400 mg C m^{-2} d^{-1}) occurred at station N18 on May 19, 1998 and corresponded with the highest chlorophyll *a* values observed at nearfield stations during this reporting period (February to late-July). Areal production declined slightly at station N04 in June but decreased to less than 200 mg C m^{-2} d^{-1} at station N18. Production at both stations remained below 200 mg C m^{-2} d^{-1} during the July surveys.

At the Boston Harbor productivity/respiration station (F23), areal production was relatively low (~100 mg C m^{-2} d^{-1}) during February and March and increased only slightly (124 mg C m^{-2} d^{-1}) in April (WF984). Areal production reached a maximum value of 1103.9 mg C m^{-2} d^{-1} at station F23 during the June survey (WF987). The production data are in agreement with the chlorophyll data, which indicated that a phytoplankton bloom occurred during this period.

Relative to other years, areal production at all three survey stations was very low. No winter/spring phytoplankton bloom was observed at any station during the sampling period (Figure 5-2). In general, nearfield stations are characterized by the occurrence of a winter/spring phytoplankton bloom, while a gradual pattern of increasing areal production from winter through summer is more typical of the harbor (station F23). The winter/spring phytoplankton blooms observed at nearfield stations in 1995-1997 generally reached values of 1000 to 4000 mg C m^{-2} d^{-1}, with blooms typically lasting 2-3 months. The absence of a winter/spring phytoplankton bloom during 1998 is being further examined and represents a major change in the seasonal productivity pattern relative to other years for the nearfield region.

The productivity cycle at station F23 was also aberrant during February to July 1998. Production values did not increase gradually over time and the peak production observed was considerably lower than earlier years (Figure 5-2). During 1995-1997, peak areal productions at station F23 ranged from 2000 to 5000 mg C m^{-2} d^{-1} in June-July. The peak areal production that was observed in June 1998 at station F23 was 2-5 times lower than peak values observed in previous years.

The relatively low production values at stations F23, N04 and N18 are consistent with the low chlorophyll values observed during the survey period.

Chlorophyll-specific areal production (Figure 5-3) was highly variable at station N18, but showed a gradual-decreasing trend over time at station N04. Chlorophyll-specific areal production was relatively low and constant at station F23 throughout the sampling cycle. Chlorophyll-specific production is an approximate measure for the efficiency of production and frequently reflects nutrient conditions at the sampling sites. The distribution of chlorophyll-specific production indicates that the efficiency of production was high relative to the amount of biomass present at the nearfield stations. At station N18, chlorophyll-specific production was greater than 600 mg C mg Chl a^{-1} d^{-1} during the early May survey (WN985). This period of high productivity per unit chlorophyll preceded the peak production observed at station N18 in mid-May (WN986) and agrees with the seasonal trend in phytoplankton abundance.

5.1.2 Chlorophyll-Specific Production

The spatial and temporal distribution of production and chlorophyll-specific production on a volumetric basis were summarized by contouring production over the sampling period (Figures 5-4 to 5-7). Chlorophyll-specific productions (daily production normalized to chlorophyll concentration at each depth) were calculated to compare production with chlorophyll concentrations. Chlorophyll-specific production can be used as an indicator of the optimal conditions necessary for photosynthesis.

Daily production was concentrated in the upper 5-10 m of the water column during the initial five surveys. A subsurface (10-20 m) productivity maximum was measured at station N18 on May 19, 1998 (WN986). A subsurface production maximum was also observed at station N04 during the May 19, 1998 survey. However, the peak depth of occurrence was observed at ~ 8 m (Figures 5-4 and 5-5). At the two nearfield stations, productions tended to increase during the spring with peak values occurring in May (station N18) and June (station N04) 1998 for the study period. For station N04, the highest production value observed (63.9 mg C m^{-3} d^{-1}) occurred at the surface on June 22, 1998 (WF987). The peak production (34.7 mg C m^{-3} d^{-1}) for station N18 occurred in surface waters on May 1, 1998 (WN985). Peak production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements. The productivity pattern observed in 1998 was very different from that observed in prior years. Peak productions typically occur during the winter/spring phytoplankton bloom period rather than gradually increasing throughout the spring season.

Chlorophyll-specific production at stations N04 and N18 was also concentrated in the upper portions of the water column (Figures 5-6 and 5-7). Peak chlorophyll-specific productions tended to occur early in the sampling season at station N04, suggesting that the efficiency of photosynthesis decreased slightly with time. When the efficiency of photosynthesis is high but not reflected in higher phytoplankton biomass (measured as total chlorophyll *a*) it suggests that other processes (such as predation by zooplankton) are important in controlling the patterns observed.

5.2 Respiration

Respiration measurements were made at the same nearfield (N04, N18) and farfield (F23) stations as productivity and at an additional station in Stellwagen Basin (F19). All four stations were sampled during each of the combined farfield/nearfield surveys and stations N04 and N18 were also sampled during the five nearfield surveys. Respiration samples were collected from three depths (surface, mid-depth, and bottom) and were incubated in the dark at *in situ* temperatures for 8±1 days.

Both respiration (in units of $\mu MO_2\ hr^{-1}$) and carbon-specific respiration ($\mu MO_2\ \mu MC^{-1}\ hr^{-1}$) rates are presented in the following sections. Carbon-specific respiration was calculated by normalizing respiration rates to the coincident particulate organic carbon (POC) concentrations. Carbon-specific respiration rates provide a relative indication of the biological availability (labile) of the particulate organic material for microbial degradation.

5.2.1 Water Column Respiration

Due to electrical problems with the incubators in June, there are only three sets of respiration data for the farfield stations (F23 and F19). Thus, all of the farfield respiration data was collected prior to the establishment of seasonal stratification. Evaluations of the temporal trends are therefore focused on the nearfield area where data are available over the whole February to July time period.

During the surveys conducted in February to April, respiration rates were generally low throughout the region (<0.10 $\mu MO_2\ hr^{-1}$) and there were no consistent vertical trends in the data (Figure 5-8). Surface water respiration rates during the first two surveys were variable and were not consistent with concurrent respiration data from the other depths or the POC data collected at station F23. These data are suspected to be erroneous.

In early May (WN985), there was an increase in the respiration rates for the surface and mid-depth samples in the nearfield area. This increase coincided with the onset of seasonal stratification and increases in productivity, POC concentration, and phytoplankton abundance. By mid-May (WN986), respiration rates had decreased to <10 $\mu MO_2\ hr^{-1}$ over the water column at station N04, but had increased at station N18 to 10-15 $\mu MO_2\ hr^{-1}$ at all three depths sampled. During this survey, the highest production rates for this time period were observed at stations N04 and N18, while at station N04 there was also a significant decrease in both POC concentration and phytoplankton abundance from the levels that had been observed in early May.

The highest respiration rates for this reporting period were observed during the two surveys in July. Respiration rates at stations N04 and N18 ranged from 0.07-0.22 $\mu MO_2\ hr^{-1}$ and 0.08-0.32 $\mu MO_2\ hr^{-1}$, respectively. The rates generally decreased with depth, which is consistent with the relatively high surface to mid-depth chlorophyll concentrations that were seen during these July surveys.

5.2.2 Carbon-Specific Respiration

Carbon-specific respiration accounts for the effect variations in the size of the particulate organic carbon (POC) pool have on respiration. Differences in carbon-specific respiration result from variations in the quality of the available particulate organic material or from environmental conditions such as temperature. Particulate organic material that is more easily degraded (more labile) will result in higher carbon-specific respiration. In general, newly produced organic material is the most labile. Water temperature is the main physical characteristic that controls the rate of microbial oxidation of organic material – the lower the temperature the lower the rate of oxidation. When stratified conditions exist, the productive, warmer surface and/or mid-depth waters usually exhibit higher carbon-specific respiration rates and bottom waters have lower carbon-specific respiration rates due to both lower water temperature and lower substrate quality due to the degradation of particulate organic material during sinking.

There was a general increase in POC concentrations from February to July (Figure 5-9), which is consistent with the increase observed in chlorophyll over this time period. POC concentrations were low (10-20 μMC) in the nearfield during the first four surveys and relatively uniform over the well-mixed water column. Over the same time period, POC concentrations were significantly higher at the harbor station F23. The carbon-specific respiration rates were low (<0.005 μMO_2 μMC^{-1} hr^{-1}) at all three stations, except for the station F23 surface water sample from WF981 discussed previously (Figure 5-10). This suggests that the POC measured at station F23 was probably degraded or detrital material transported from the harbor or other coastal areas.

In early May (WN985), POC concentrations had increased at both nearfield stations to approximately 20-30 μMC. This correlated to the highest surface and mid-depth carbon-specific respiration rates measured at station N04 during this time period. Low carbon-specific respiration rates were still observed at station N18 even though concurrent production measurements were the highest observed at this station. Ancillary data (low chlorophyll and low phytoplankton abundance) suggest that the sampling at station 18 may have occurred at the initiation of a localized bloom when there was relatively low, yet productive phytoplankton assemblage.

The POC concentrations had decreased by mid-May at both nearfield stations. This was concomitant with lower carbon-specific respiration at station N04, but higher carbon-respiration for the mid-depth and bottom samples at station N18. This increase in respiration at depth was coincident with high subsurface production (see Figure 5-5). Though POC concentrations decreased to approximately 10 μMC in the bottom water in June and July, carbon-specific respiration remained high. This suggests that the limited particulate organic material reaching the bottom waters had not been substantially degraded or that there was another significant pool of labile organic carbon that has not been considered (dissolved organic carbon).

5.3 Plankton Results

Plankton samples were collected on each of the nine surveys conducted during this reporting period. Phytoplankton and zooplankton samples were collected at two stations during each nearfield survey and at 11 stations during the farfield surveys. During the first three farfield surveys of 1998 (WF981, WF982, and WF984), zooplankton samples were collected at two additional stations in Cape Cod Bay (F32 and F33). Phytoplankton samples included both whole-water and 20 μm-mesh screened samples, from the surface and subsurface chlorophyll maximum depths. Zooplankton samples were collected by vertical/oblique tows with 102 μm-mesh nets. Methods of sample collection and analyses are detailed in Albro *et al*. (1998).

In this section, the seasonal trends in plankton abundance and regional characteristics of the plankton assemblages are evaluated. Total abundance and relative abundance of major taxonomic group are presented for each phytoplankton and zooplankton community. Tables in the appendices provide data on cell densities and relative abundance for all dominant plankton species (>5% abundance): Appendix F – whole water phytoplankton, Appendix G – 20-μm screened phytoplankton, and Appendix H – zooplankton.

5.3.1 Phytoplankton

5.3.1.1 Seasonal Trends in Total Phytoplankton Abundance

Total phytoplankton abundances in nearfield whole water samples (surface and subsurface mid-depths) were low from February through early April (Table 5-1). Total abundances increased in May and June, to levels in July that were the highest observed during this period. Instead of a typical winter/spring phytoplankton bloom, there was a sustained increase from February through July.

Total phytoplankton abundance in farfield whole water samples (surface and subsurface mid-depths) showed similar low abundances through early April, with seasonal increases through June (Table 5-1).

Total abundances of dinoflagellates, silicoflagellates and protozoans in 20 µm-mesh-screened water samples were considerably lower than those recorded for total phytoplankton in whole-water samples, due to the screening technique which selects for larger, albeit rarer cells. Nonetheless, similar seasonal increases, though of different taxa, were recorded. Nearfield screened phytoplankton increased from February through May to high levels in June and July (Table 5-2). These increases in screened phytoplankton abundance largely reflected a sustained bloom of the dinoflagellates *Ceratium longipes, Ceratium tripos*, and other species of this genus from February through July.

Table 5-1. Nearfield and Farfield Averages and Ranges of Abundance (10^6 Cells L^{-1}) of Whole-Water Phytoplankton

Survey	Dates (1998)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF981	2/3-2/10	0.297	0.055-0.579	0.432	0.173-0.887
WF982	2/27-3/2	0.333	0.211-0.457	0.576	0.301-1.274
WN983	3/24	0.532	0.405-0.614	NA	NA
WF984	3/31-4/3	0.351	0.280-0.477	0.772	0.232-2.509
WN985	5/1	1.119	0.593-2.220	NA	NA
WN986	5/19	0.794	0.581-1.231	NA	NA
WF987	6/16-19, 6/22	0.890	0.148-2.033	2.042	0.158-4.932
WN988	7/8, 7/13	2.356	1.142-3.310	NA	NA
WN989	7/23	1.904	1.379-2.462	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

Table 5-2. Nearfield and Farfield Average and Ranges of Abundance (Cells L^{-1}) for >20 µM-Screened Phytoplankton

Survey	Dates (1998)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF981	2/3-2/10	166	120-247	112	22-456
WF982	2/27-3/2	188	93-303	98	36-148
WN983	3/24	514	581-790	NA	NA
WF984	3/31-4/3	1,715	1,431-2,023	586	76-1,766
WN985	5/1	1,726	574-2,307	NA	NA
WN986	5/19	1,934	201-3,455	NA	NA
WF987	6/16-19, 6/22	4,238	1,116-13,757	2,289	314-11,796
WN988	7/8, 7/13	3,193	1,134-5,164	NA	NA
WN989	7/23	3,351	1,703-6,775	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton - During February – March (WF981 and WF982), nearfield whole-water phytoplankton assemblages from both depths were dominated by unidentified microflagellates and cryptomonads < 10 µm in longest dimension (Figures 5-11 and 5-12). Small centric diatoms < 10 µm in diameter were subdominants in surface samples from stations N04 and N18, whereas an unidentified species of the dinoflagellate genus *Gymnodinium* was subdominant at mid-depths at these same stations.

During March – April (WN983 and WF984), the overwhelming nearfield dominance of < 10 µm microflagellates and cryptomonads continued in the nearfield, although *Gymnodinium* sp. was again a subdominant at subsurface depths.

In WN985 the nearfield samples were still dominated by small microflagellates and cryptomonads, but the bloom of chain-forming diatoms such as *Chaetoceros socialis* and *Skeletonema costatum* was evidenced in the nearfield. The increase in *Chaetoceros socialis* and *Skeletonema costatum* in the nearfield continued through late May during WN986, but with unidentified centric diatoms < 10 µm in diameter and a small (< 20 µm diameter) species of the diatom genus *Thalassiosira* and *Gymnodinium* sp. joining *Skeletonema costatum* as subdominants.

During the June survey (WF987), nearfield assemblages from both depths included a mixture of small microflagellates and chain-forming diatoms such as *Skeletonema costatum, Chaetoceros* spp., and *Pseudonitzschia delicatissima*.

By WN988 in early July, whole-water assemblages were dominated by microflagellates < 10 µm in size, and a mixture of subdominant diatoms such as *Leptocylindrus minimus, L. danicus, Rhizosolenia fragilissima, Proboscia* (formerly *Rhizosolenia*) *alata*, and *Skeletonema costatum*.

In late July Nearfield survey during WN989, surface assemblages were dominated by small microflagellates, and secondarily by the chain-forming diatoms *Leptocylindrus danicus* and *L. minimus*. Subdominance in subsurface mid-depths had shifted, however, to an unidentified species of *Gymnodinium*.

Based on analyses since 1992, the whole-water phytoplankton assemblage in the nearfield was typical for the first half of the year during non-*Phaeocystis* years in terms of taxonomic composition. However it was atypical in the respect that there was no clear spring phytoplankton bloom, but rather a continuous increase in phytoplankton abundance from winter through early summer.

Screened Phytoplankton - During WF981 nearfield screened samples were overwhelmingly dominated by the silicoflagellate *Distephanus speculum*, and secondarily by the thecate dinoflagellates *Ceratium tripos* and, at various stations, by *C. longipes* and *Dinophysis acuminata*. The ciliate protozoan *Mesodinium rubrum* was also abundant.

In WF982, *Ceratium longipes* and *C. tripos* were dominant with *Distephanus speculum* and *Mesodinium rubrum* subdominant in surface samples, but the *Ceratium* species were clearly dominant at depth.

By WN983, *Ceratium tripos* and *C. longipes* completely dominated the nearfield samples at both depths.

In WF984, *Ceratium longipes* dominated nearfield samples from both depths, with subdominant contributions from other *Ceratium* species.

In WN985, dominance by *Ceratium longipes* and other congeners, particularly *C. tripos* and *C. furca*, continued, but the thecate dinoflagellates *Dinophysis norvegica* and species of *Protoperidinium* were subdominant, particularly at depth. These patterns held in WN986, with *Ceratium* dominance at both depths, at both nearfield stations, and *Dinophysis norvegica* most abundant at depth.

Similar dinoflagellate dominance continued in May and June. During WF987, nearfield station assemblages were dominated by several species of *Ceratium* (*fusus, lineatum, longipes, tripos*) and *Dinophysis norvegica*. During WN988, dominance by *Ceratium fusus, C. lineatum*, and *C. tripos* continued, with additional contributions from *Protoperidinium trochoidium* and *Dinophysis norvegica*. During WN989, screened samples were dominated by the same species in the previous surveys (*C. fusus, C. lineatum, C. tripos, D. norvegica*, and *P. trochoidium*).

In comparison with other years, the screened phytoplankton in the nearfield was typical for this time of year, except that the bloom of *Ceratium tripos/longipes* was initiated earlier than in some other years, and became the major feature of the screened-water dinoflagellate assemblage.

5.3.1.3 Regional Phytoplankton Assemblages

Whole-Water Phytoplankton - During WF981 and WF982, most farfield station assemblages were dominated at both depths by unidentified microflagellates and cryptomonads < 10 µm in cell size. However, the diatom *Skeletonema costatum* was the dominant at stations F01 and F02 in Cape Cod Bay (Figures 5-13 and 5-14).

During WF984 (Figure 5-15) most farfield stations were dominated by unidentified microflagellates and cryptomonads < 10 µm in size, but chain-forming diatoms were increasing in abundance. Particularly, these included *Chaetoceros compressus* at station F01 and other small *Chaetoceros* and unidentified centric diatoms < 10 µm in individual cell diameter at several other stations. *Skeletonema costatum* was also a subdominant at various stations in Boston Harbor such as F23, F30, and F31, and in Cape Cod Bay at F01 (both depths) and F02 (chlorophyll maximum).

By WF987 dominance of assemblages at both depths at most farfield stations had shifted from microflagellates and cryptomonads to a mixture of chain-forming diatoms (Figure 5-16). Included were several species of the genus *Chaetoceros, Skeletonema costatum*, and others.

Whole-water phytoplankton assemblages at farfield stations were similar to those in the nearfield, in terms of composition, and absence of a clear spring phytoplankton bloom.

Screened Phytoplankton - In WF981, 20 µm-screened surface phytoplankton samples were dominated by the silicoflagellates *Distephanus speculum* and *Dictyocha fibula*, and to a much lesser extent, at various stations, by several species of the dinoflagellate genus *Ceratium* (*C. furca, C. fusus, C. longipes*, and *C. tripos*). An unidentified athecate dinoflagellate was the second most abundant component of the screened surface samples at station F23 in Boston Harbor. The ciliate protozoan *Mesodinium rubrum* was also abundant, comprising > 40% of cells counted at station F01 in Cape Cod Bay. These patterns from surface samples generally held for subsurface depths, except that the dinoflagellate *Prorocentrum micans* comprised > 22% of cells counted at station F25.

In WF982 *Distephanus speculum*, and to a lesser extent, *Mesodinium rubrum* were still abundant at both depths at most stations, but that dominance was shared with increasing proportions of *Ceratium longipes* and *C. tripos*.

In WF984, surface and subsurface samples were overwhelmingly dominated by *Ceratium longipes*, and secondarily by *C. tripos, C. fusus*, and other species of this genus. An unidentified athecate dinoflagellate was subdominant at stations F30 and F31 in Boston Harbor.

Screened samples in WF987 were dominated by several species of the dinoflagellate genus *Ceratium* (*fusus, lineatum, longipes, tripos*) and other dinoflagellates such as *Dinophysis norvegica, Protoperidinium pallidum*, and *P. trochoidium*.

Screened-water dinoflagellate assemblages at farfield stations were similar to those in the nearfield, particularly in terms of the sustained bloom of *Ceratium tripos/longipes*.

5.3.1.4 Nuisance Algae

There were no blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – July, 1998. Some species that have caused harmful blooms in previous years, such as *Phaeocystis pouchetti*, were unrecorded during this period. Potentially-toxic species such as *Alexandrium tamarense* and members of the genus *Pseudo-nitzschia* were only sporadically present in low numbers. Similarly, non-toxic species whose blooms have caused anoxic events elsewhere, such as *Distephanus speculum* (Fanuko, 1989) and *Ceratium tripos*(/*longipes*) (Malone, 1978; Falkowski *et al*. 1980) were not recorded at abundances approaching those previously associated with anoxia. A summary is presented below.

Alexandrium tamarense was sporadically recorded for screened samples at a few stations during April and May (WF984, WN985), but only at trace abundances of 2-5 cells L^{-1}. This dinoflagellate was again recorded in June and July (WF987, WN988, WN989), but only at approximate abundances of < 10 cells L^{-1}.

Pseudo-nitzschia spp. were identified in the nearfield rapid analysis samples in all surveys except WF981, but except for values of 2-3 x 10^3 cells L^{-1} during WN988, this genus was only present at approximate levels of 1.5 x 10^3 cells L^{-1}, and usually < 0.5 x 10^3 cells L^{-1}. Although the non-toxic species *P. delicatissima* was identified with confidence, species reported as *P. pungens* could be either non-toxic *P. pungens*, or domoic-acid-producing *P. multiseries*, but it is impossible to distinguish the two without performing scanning electron microscopy counts on intercostal poroids on the underside of acid-washed thecae. Nonetheless, even if these were *P. multiseries*, their abundances were two orders of magnitude below the 10^5 cells L^{-1} threshold for domoic acid toxicity used in Canadian waters.

Perhaps the singular phytoplankton event of this period was the bloom of *Ceratium longipes/C. tripos*, which began unusually early in February, and exhibited sustained increases through July. Observations by Turner during the sampling for the ECOHAB (Ecology and Oceanography of Harmful Algal Blooms) program in the Gulf of Maine revealed that this bloom extended far to the north and east along the coast of Maine into the Bay of Fundy, in July and August of 1998. Although abundances of *C. longipes* and *C. tripos* recorded for screened samples during WF981 - WN983 (February – March) were < 515 cells L^{-1}, in April and May (WF984, WN985, WN986) maximum levels were 1-2 x 10^3 cells L^{-1}. In June and July (WF987, WN988, WN989) maximum abundances were 2.5-3.1 x 10^3 cells L^{-1}.

Ceratium longipes and *C. tripos* usually bloom in Massachusetts and Cape Cod Bays during the spring and summer, but the early initiation of this bloom in 1998 may relate to the unusually mild El Niño winter in New England in 1998. Nonetheless, abundances recorded here are well below those associated with the 1976 bloom of *C. tripos* blamed for widespread anoxia in the New York Bight. During that bloom, early March levels of *C. tripos* were an order-of-magnitude higher than "normal" levels of 1-5 x 10^2 cells L^{-1} (Falkowski et al. 1980). By June, 1976, abundances associated with anoxia reached 5 x 10^5 cells L^{-1}, although most values were 10-400 x 10^3 cells L^{-1} (average = 240 x 10^3 cells L^{-1}) (Malone, 1978). Thus, levels of *C. tripos* and *C. longipes* in Massachusetts Bay in 1998 (maxima < 3 x 10^3 cells L^{-1}) were far below those in the New York Bight in 1976.

Although the 1976 New York Bight bloom has been attributed only to *Ceratium tripos*, summer *Ceratium* blooms in Massachusetts and Cape Cod Bays are usually combined blooms of the morphologically-similar congeners *C. tripos* and *C. longipes*, with the latter most abundant. Although *C. longipes* is not mentioned in major papers describing the 1976 bloom in the New York Bight (Falkowski *et al*. 1980; Malone, 1978; Malone *et al*. 1979), photographs of putative *"C. tripos"* presented in Falkowski *et al*. (1980) (Fig. 12, p. 493) and Malone *et al*. (1979) (Plate 1, p. 218) are clearly those of *C. longipes*, not *C. tripos*. Thus, the 1976 New York Bight *Ceratium* bloom was apparently due to a combination of C. *tripos* and C. *longipes*, as is typical for blooms in Massachusetts and Cape Cod Bays.

Another non-toxic phytoplankton reported to cause anoxic blooms is the silicoflagellate *Distephanus speculum*. During an anoxia-inducing bloom in August, 1983 in the Gulf of Trieste (Adriatic Sea), *D. speculum* abundances were 4-653 x 10^3 cells L^{-1} (Fanuko, 1989). Levels of this species in screened samples from Massachusetts Bay during WF981 – WF987 were < 0.5 x 10^3 cells L^{-1}, and usually < 0.1 x 10^3 cells L^{-1}.

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations generally increased from February through April, reached the highest numbers in mid-May coinciding with the productivity maximum (WN986), and remained moderately high in June and July (Table 5-3).

Total zooplankton abundance at farfield stations was generally low (< 20 x 10^3 animals m^{-3}) in February (Table 5-3). However, at stations F02, F33, and particularly F32 in the eastern side of Cape Cod Bay, values were high, ranging from 24.3-56.2 x 10^3 animals m^{-3} (Figure 5-17). By late February to early March, total zooplankton abundance at farfield stations had generally increased, with values at half the stations >20 x 10^3 animals m^{-3}. Only at the three stations in Boston Harbor (F23, F30, and F31) were all values <10 x 10^3 animals m^{-3} (Figure 5-18). The spring increase in farfield zooplankton abundance continued through late March-early April, with most values >20-30 x 10^3 animals m^{-3} (Figure 5-19). By June, zooplankton abundance was high (>10 x 10^3 animals m^{-3}) at all stations, with an astonishing maximum of 289.8 x 10^3 animals m^{-3} at station F23 in Boston Harbor (Figure 5-20).

Table 5-3. Nearfield and Farfield Average and Ranges of Abundance (10^3 Animals M^{-3}) for Zooplankton

Survey	Dates (1998)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF981	2/3-2/10	8.5	3.0-12.9	15.5	1.2-56.2
WF982	2/27-3/2	23.5	9.2-33.0	21.6	4.8-57.2
WN983	3/24	29.5	28.7-30.4	NA	A
WF984	3/31-4/3	48.4	42.1-56.0	27.7	1.5-71.0
WN985	5/1	20.8	10.0-31.5	NA	NA
WN986	5/19	62.3	52.0-72.7	NA	NA
WF987	6/16-19, 6/22	48.8	23.3-69.8	59.2	14.6-289.8
WN988	7/8, 7/13	30.5	28.7-32.2	NA	NA
WN989	7/23	35.6	26.8-44.3	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

5.3.2.2 Nearfield Zooplankton Community Structure

During WF981 the nearfield zooplankton assemblages were dominated by copepod nauplii, and females and copepodites of *Oithona similis* (stations N16 and N04), although gastropod veligers comprised 19% of the assemblage at station N04. At station N18 copepod nauplii were 40% of the catch, but abundance of *O. similis* was low (<5%), whereas *Acartia hudsonica* females and copepodites had a combined total of 42% of animals counted.

During WF982, WN983 and WN984, the nearfield was dominated by copepod nauplii and *Oithona similis* copepodites, with gastropod veligers as subdominants, and occasional subdominant abundances by *Calanus finmarchicus* copepodites, *Pseudocalanus* copepodites, and the appendicularian *Oikopleura dioica*.

Nearfield stations during WN986 and WF987 were dominated by copepod nauplii with subdominants including bivalve veligers, and copepodites of *Oithona similis, Pseudocalanus* sp. and *Temora longicornis*. During WN988 and WN989 copepod nauplii and *O. similis* copepodites continued to dominate, with subdominant contributions by *Oikopleura dioica*, bivalve veligers and *Pseudocalanus* and *Temora longicornis* copepodites.

5.3.2.3 Regional Zooplankton Assemblages

farfield stations during survey WF981, copepod nauplii and *Oithona similis* females and copepodites were dominants. *Pseudocalanus* copepodites were also subdominants at most stations. *Acartia hudsonica* copepodites were 6-20% of the catch at stations F31 and F23, respectively, in Boston Harbor, and barnacle naupalii were 22% of the assemblage at stations F31, and gastropod veligers made up 36% at station F30.

During WF982, copepod nauplii and *Oithona similis* copepodites were again dominant at farfield stations, but barnacle nauplii and/or gastropod veligers were subdominants at most stations. *Acartia hudsonica* were again subdominants at station F30 in Boston Harbor and, presumably reflecting the shallow depths in the harbor, polychaete larvae and harpacticoid copepods, likely of benthic origin, were subdominants at stations F30 and F31, respectively.

In WF984, copepod nauplii and *Oithona similis* copepodites were dominant at all farfield stations, except station F30, the most-inshore station in Boston Harbor. As expected, *Acartia hudsonica* copepodites were most abundant in the harbor at station F30, but surprisingly, *A. hudsonica* was either unrecorded, or present only at trace levels at the other two harbor stations (F31 and F23, respectively). Barnacle nauplii were also abundant at most stations, and sporadically dominant at some (F13, F23, F01, F25, F30, F31). Gastropod veligers were also dominant at most farfield stations, except for F23 and F30 in Boston Harbor.

During WF987 farfield zooplankton assemblages were dominated at most stations by copepod nauplii and bivalve veligers, with important subdominant contributions from copepodites of *Oithona similis, Temora longicornis* and *Pseudocalanus* sp,. *Acartia* spp. copepodites were important subdominants at stations F30 and F31 in Boston Harbor as expected, but surprisingly, not at station F23. There, the cladoceran *Evadne nordmani* and polychaete larvae shared subdominance, whereas these latter taxa were much less prominent elsewhere.

The addition of stations F32 and F33 in Cape Cod Bay during WF981, WF982, and WF983, reinforces the dominance of copepod nauplii and *Oithona similis* copepodites recorded for the previously sampled stations F01 and F02. However, addition of F32 and F33 extended the range in total abundance recorded for F01 and F02 from approximately 12,000-24,000 animals m^3 to 28,000-56,000 animals m^3 in WF981, from approximately 15,000-24,000 animals m^3 to 27,000-29,000 animals m^3 in WF982, and from approximately 13,000 animals m^3 to 19,000-28,000 animals m^3 in WF984. Thus, addition of stations F32 and F33 in Cape Cod Bay revealed a greater level of patchiness in total abundance of assemblages that were generally dominated by the same suite of taxa. Further, during WF984, abundance of *Calanus finmarchicus* copepodites comprised only about 3-4% of the catch at stations F01 and F02, but approximately 7-11% at F32 and F33. Thus, for this important forage item of right whales that feed in Cape Cod Bay during this time of the year, addition of the two new stations captured a three-fold increase in patchiness of this copepod that would have been missed by sampling only stations F01 and F02.

5.4 Summary of Water Column Biological Events

- Relative to previous years, areal production was very low at all three productivity stations (N04, N18, and F23) from February to July 1998.
- Areal production in the nearfield was <300 mgC m^{-2} d^{-1} from February to April, reached maximum values of 300-400 C m^{-2} d^{-1} in May, and decreased to <200 C m^{-2} d^{-1} in July.
- At Boston Harbor station F23, areal production was 100-125 C m^{-2} d^{-1} for February to April and reached a maximum value of 1104 C m^{-2} d^{-1} in June.
- The lack of a winter/spring phytoplankton bloom in 1998 represents a major aberration in the seasonal productivity pattern relative to previous years for the nearfield region.
- For the winter/spring period, chlorophyll-specific production was relatively high at each of the nearfield stations suggesting that nutrient conditions were not limiting productivity and that other processes (e.g. water column instability, predation by zooplankton) may be limiting production.
- Respiration rates were generally low throughout the region (<0.10 μMO_2 hr^{-1}) from February to April, increased in the nearfield area in May, and the highest respiration rates (0.22-0.32 μMO_2 hr^{-1}) for this reporting period were observed during the two surveys in July.
- There was a general increase in POC concentrations from February to July, which was consistent with the increase observed in chlorophyll over this time period.
- POC concentrations were significantly higher at the Boston Harbor station F23 than at the nearfield stations.
- Total phytoplankton abundance in the nearfield was low from February to April increasing in May, June, and July. This is atypical for this area, instead of a winter/spring phytoplankton bloom, there was a sustained increase from February through July.
- Nearfield screened phytoplankton abundance increased from February to July. This increase was the result of a sustained bloom of the dinoflagellates *Ceratium longipes*, *Ceratium tripos*, and other species of this genus from February to July.
- The nearfield phytoplankton community was dominated by microflagellates from February through May. In June and July, the whole-water assemblages were dominated by a mixture of microflagellates and chain-forming diatoms.
- Regionally there was a shift in assemblages from one dominated by microflagellates and cryptomonads in February/March to one dominated by chain-forming diatoms in June.
- There were no blooms of harmful or nuisance phytoplankton species in the region during February to July 1998. *Alexandrium tamarense* and *Pseudo-nitzschia* spp. were recorded, but only at low numbers.
- Total zooplankton abundance at nearfield stations generally increased from February through April, reached the highest numbers in mid-May that coincided with productivity maximum (WN986), and remained moderately high in June and July.
- Copepod nauplii and *Oithona similis* copepodites dominated nearfield and farfield zooplankton community composition from February through July. At the Boston Harbor stations, *Acartia hudsonica* were also subdominants.

WF981 **Station F23**

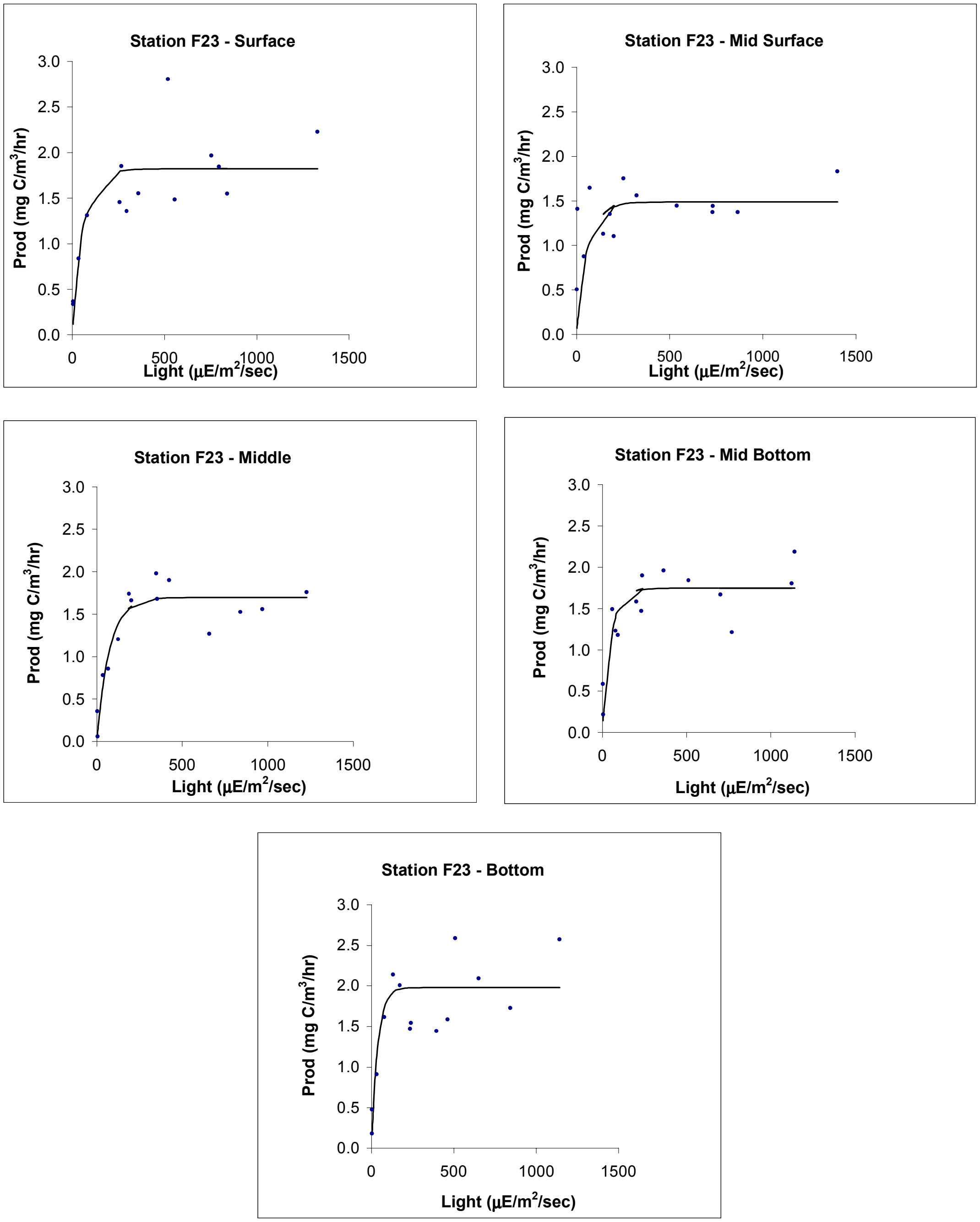


Figure 5-1. An Example Photosynthesis-Irradiance Curve From Station F23 Collected in February 1998

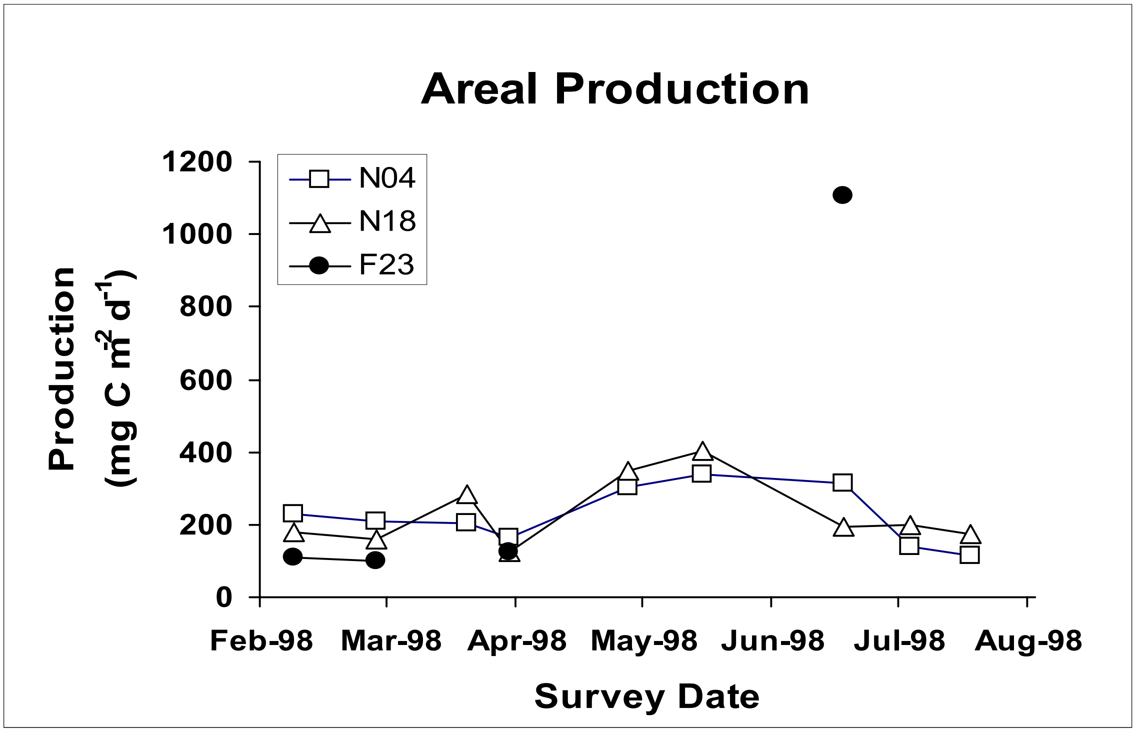


Figure 5-2. Time-Series of Areal Production ($mgCm^{-2}d^{-1}$) for Productivity Stations

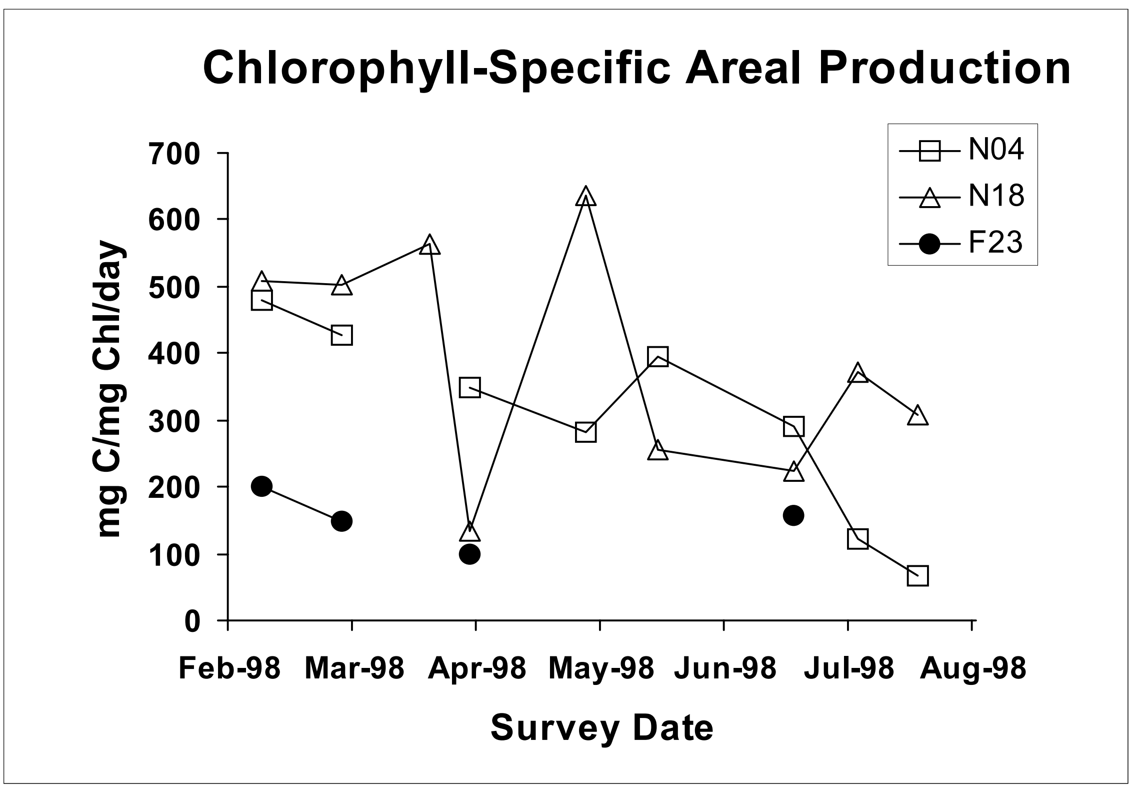


Figure 5-3. Time-Series of Chlorophyll-Specific Areal Production ($mgCmgChl^{-1}d^{-1}$) for Productivity Stations

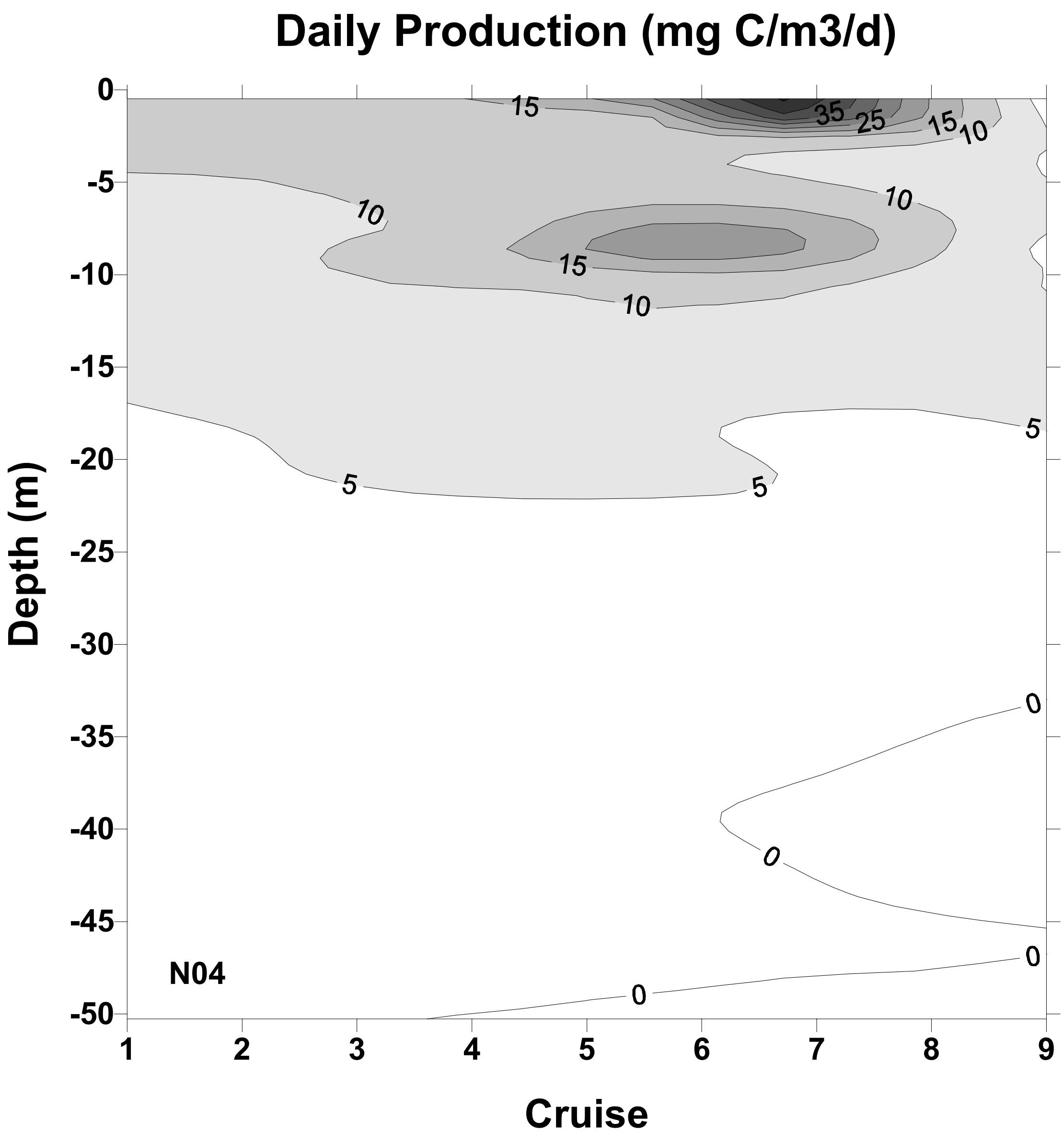


Figure 5-4. Time Series of Contoured Daily Production ($mgCm^{-3}d^{-1}$) Over Depth at Station N04

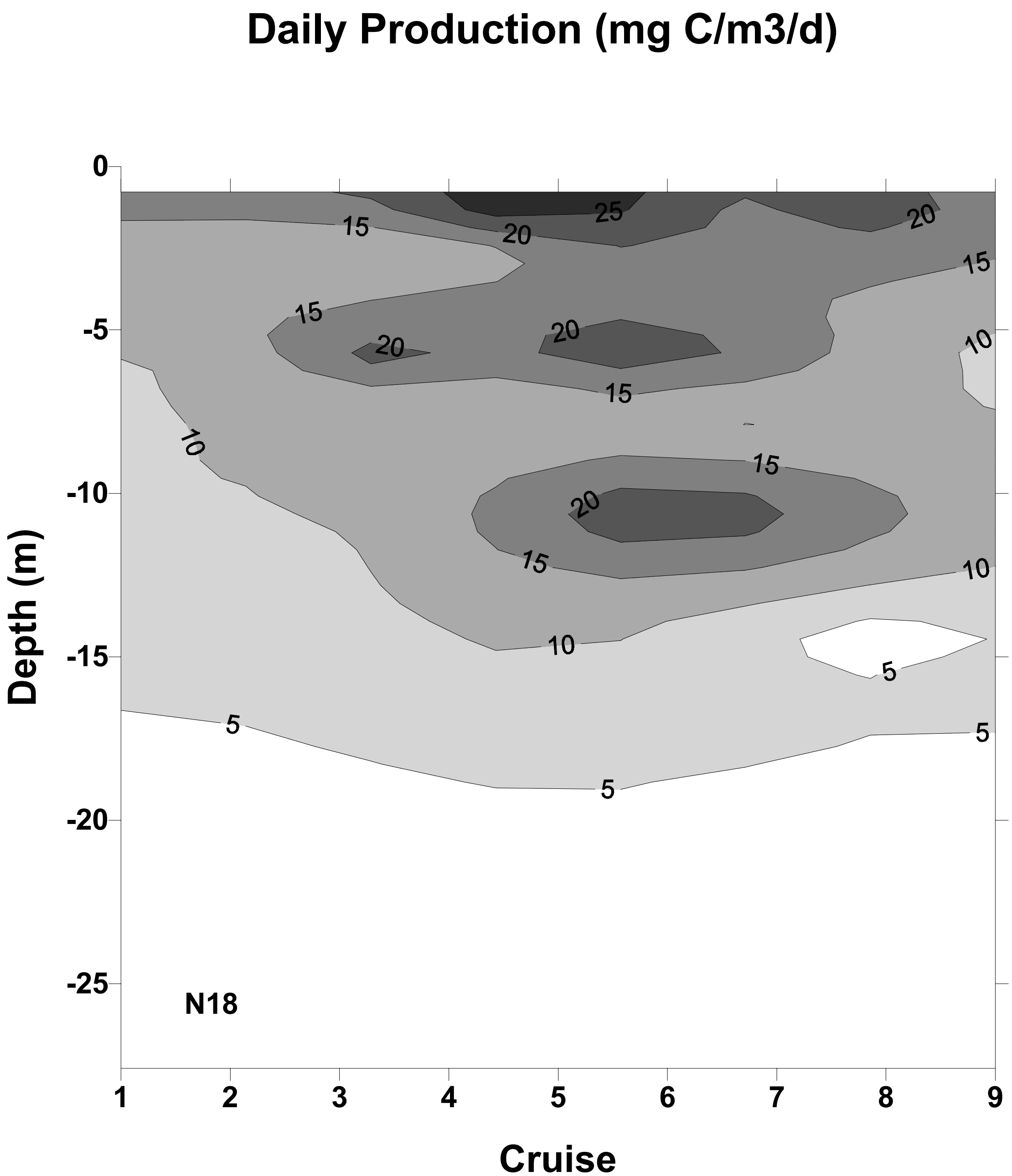


Figure 5-5. Time Series of Contoured Daily Production ($mgCm^{-3}d^{-1}$) Over Depth at Station N18

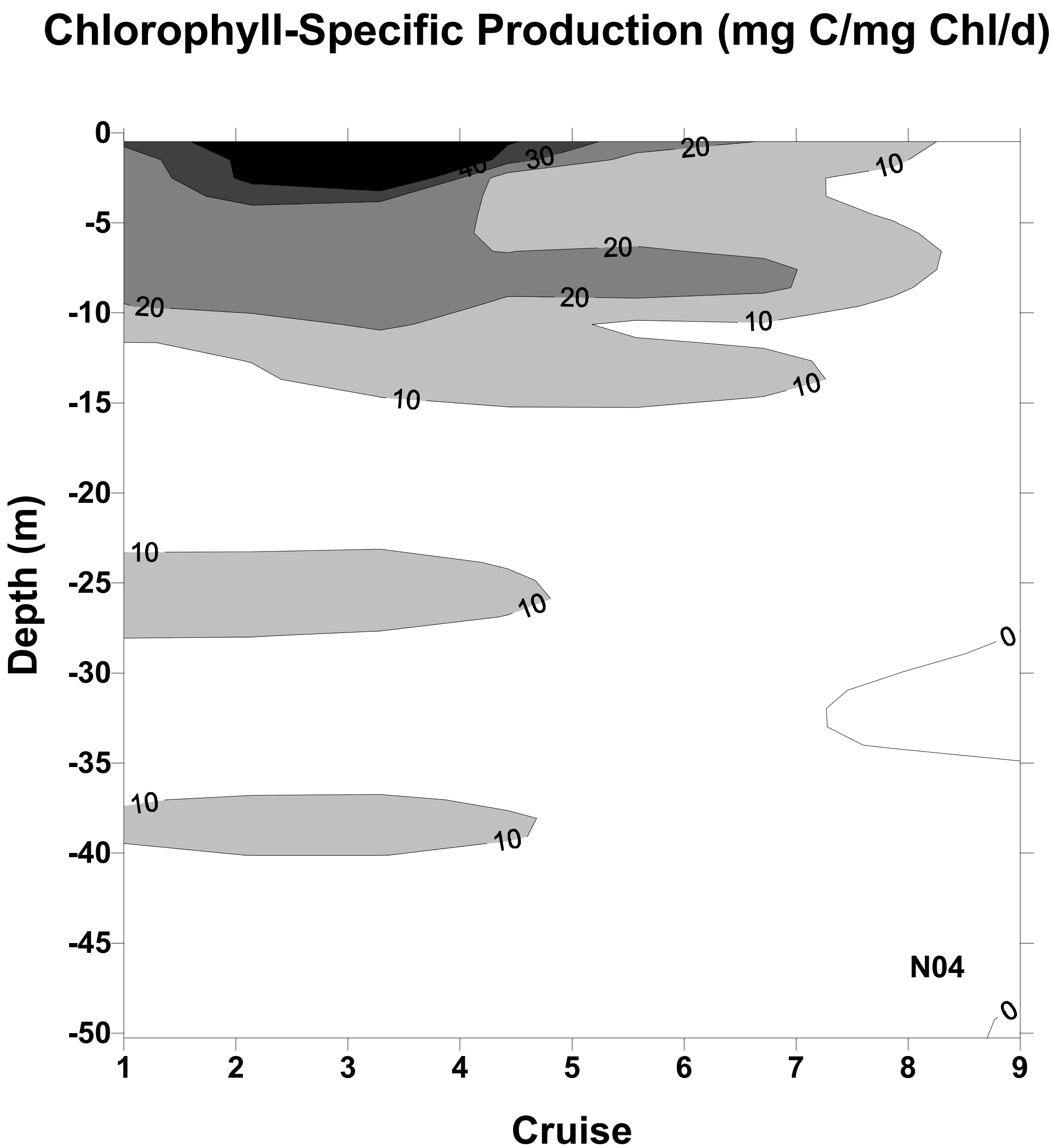


Figure 5-6. Time Series of Contoured Chlorophyll-Specific Production ($mgCmgChl^{-1}d^{-1}$) at Station N04

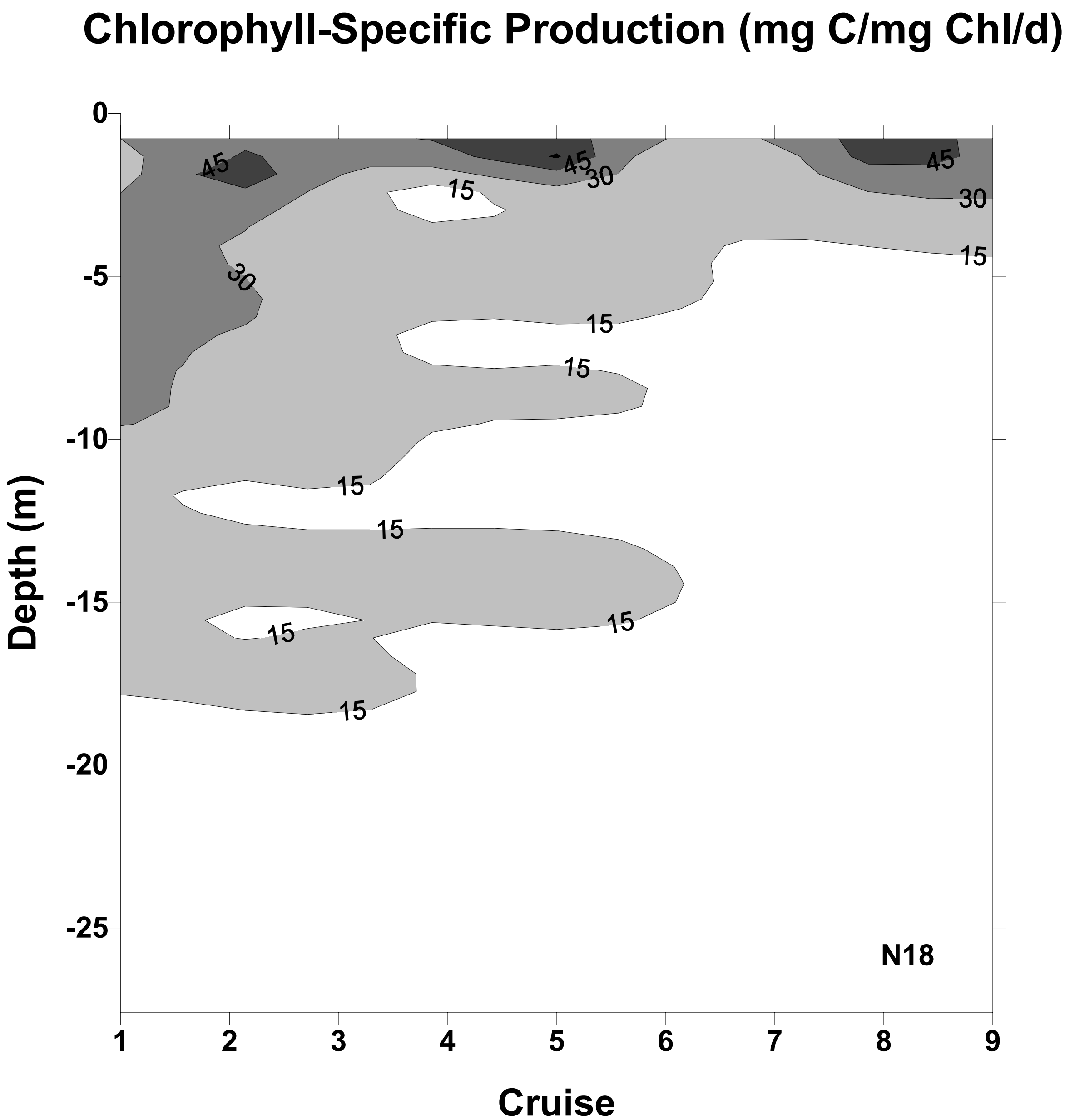


Figure 5-7. Time Series of Contoured Chlorophyll-Specific Production ($mgCmgChl^{-1}d^{-1}$) at Station N18

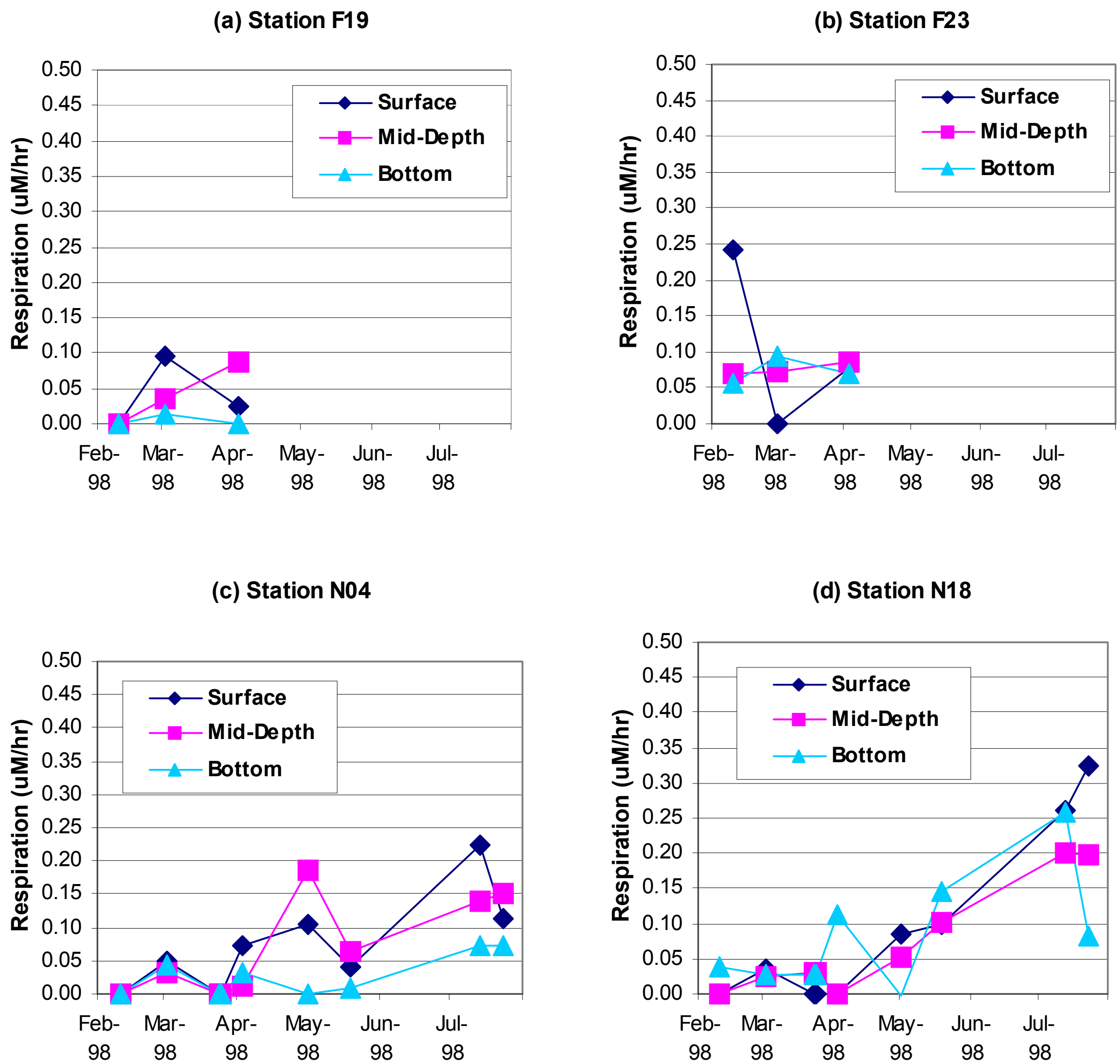
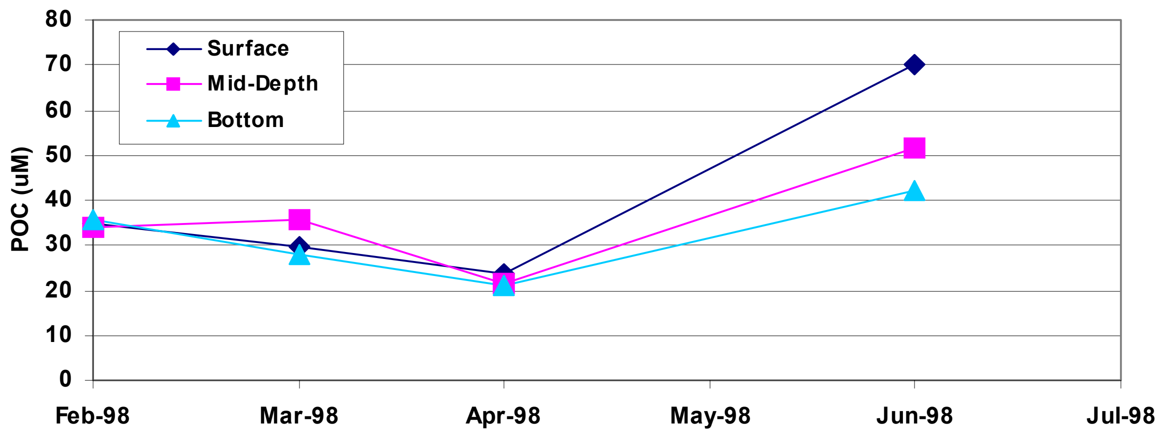
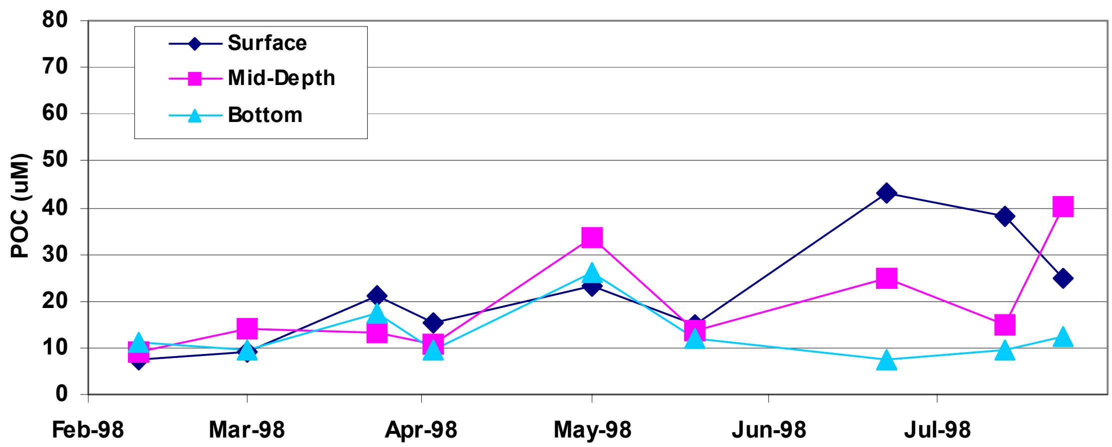


Figure 5-8. Time Series Plots of Respiration Stations F23, N02, and N18

(a) Station F23



(b) Station N04



(c) Station N18

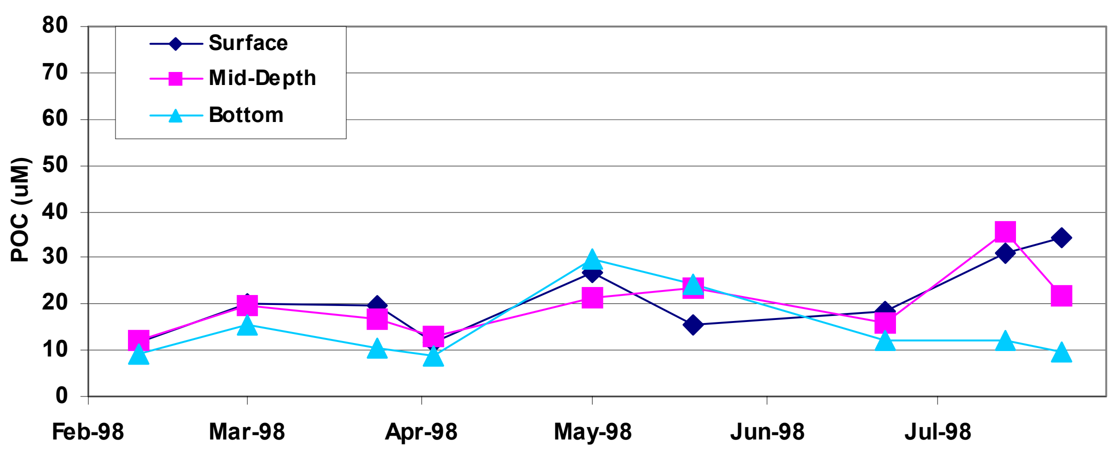


Figure 5-9. Time Series Plots of POC at Stations F23, N04, and N18

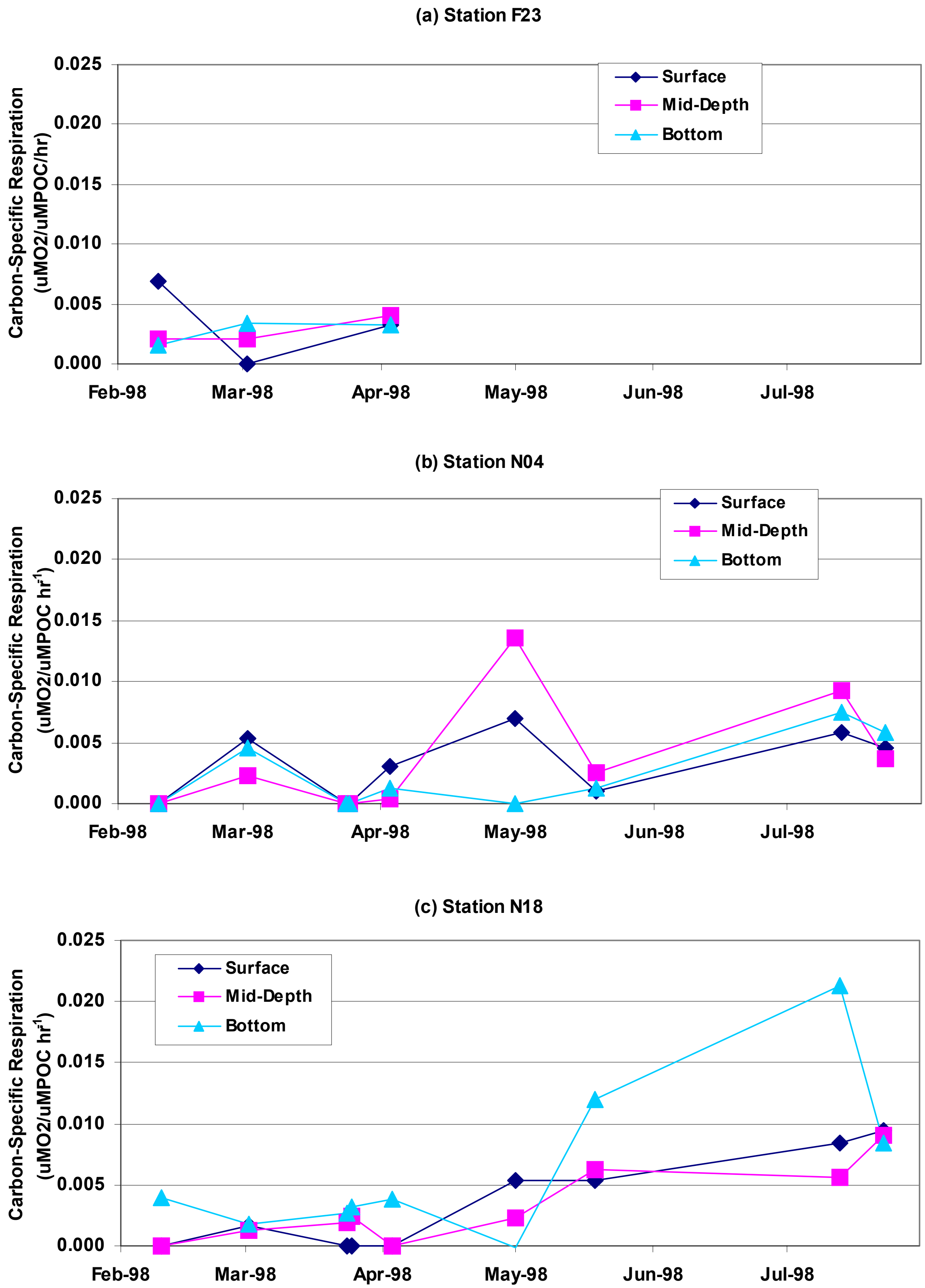


Figure 5-10. Time Series Plots of Carbon-Specific Respiration at Stations F23, N04, and N18

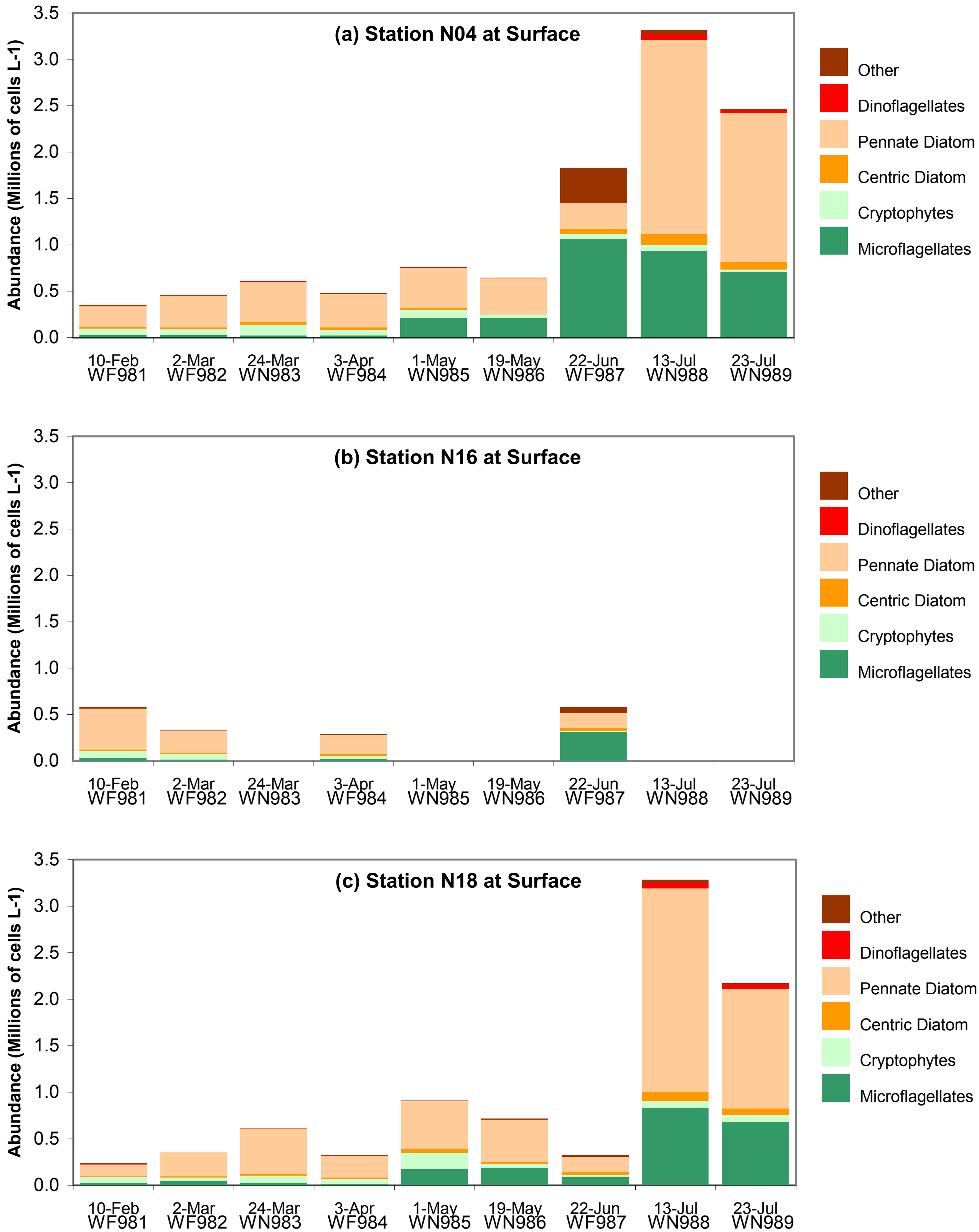


Figure 5-11. Phytoplankton Abundance By Major Taxonomic Group, Nearfield SurfaceSamples

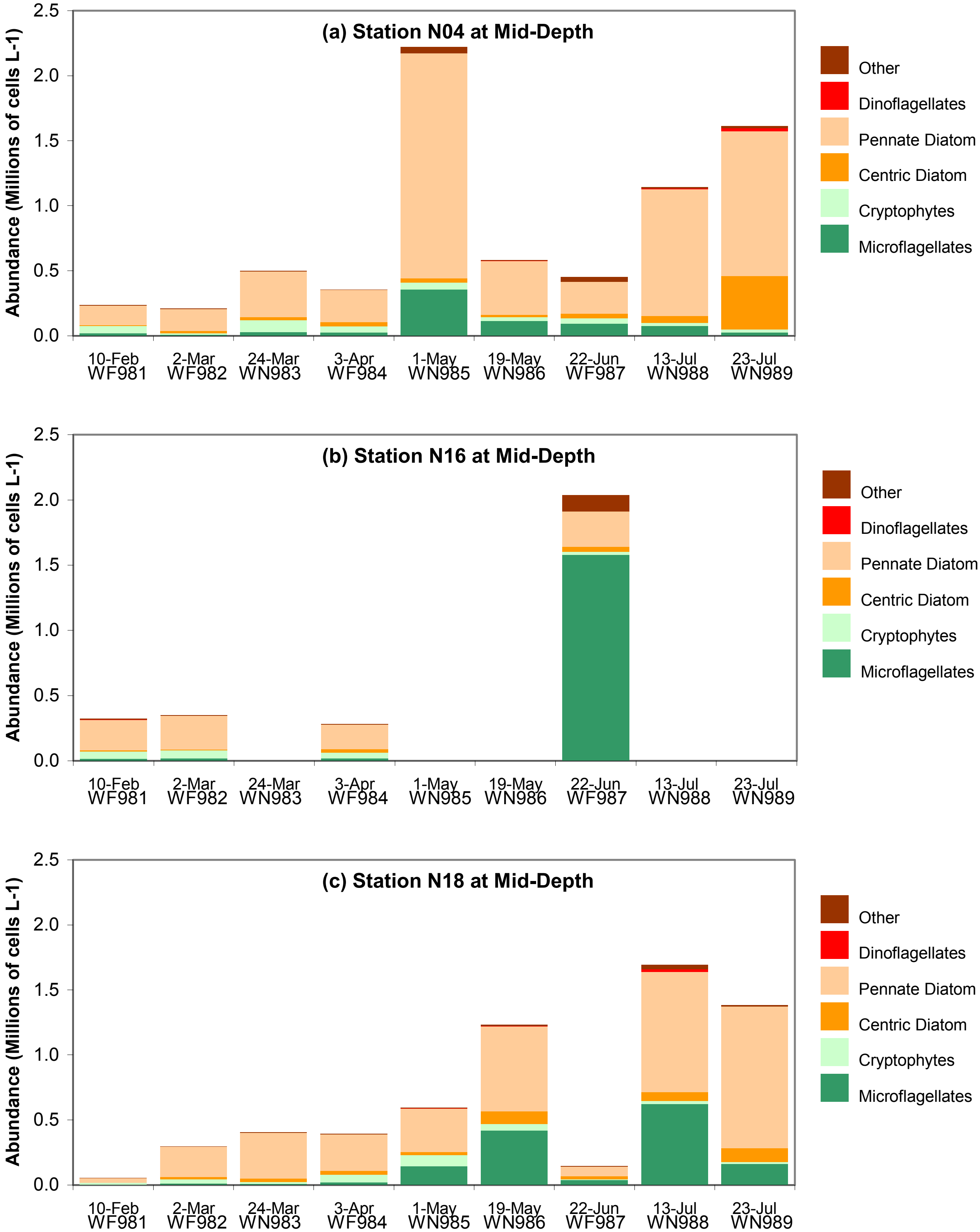


Figure 5-12. Phytoplankton Abundance By Major Taxonomic Group, Nearfield Mid-Depth Samples

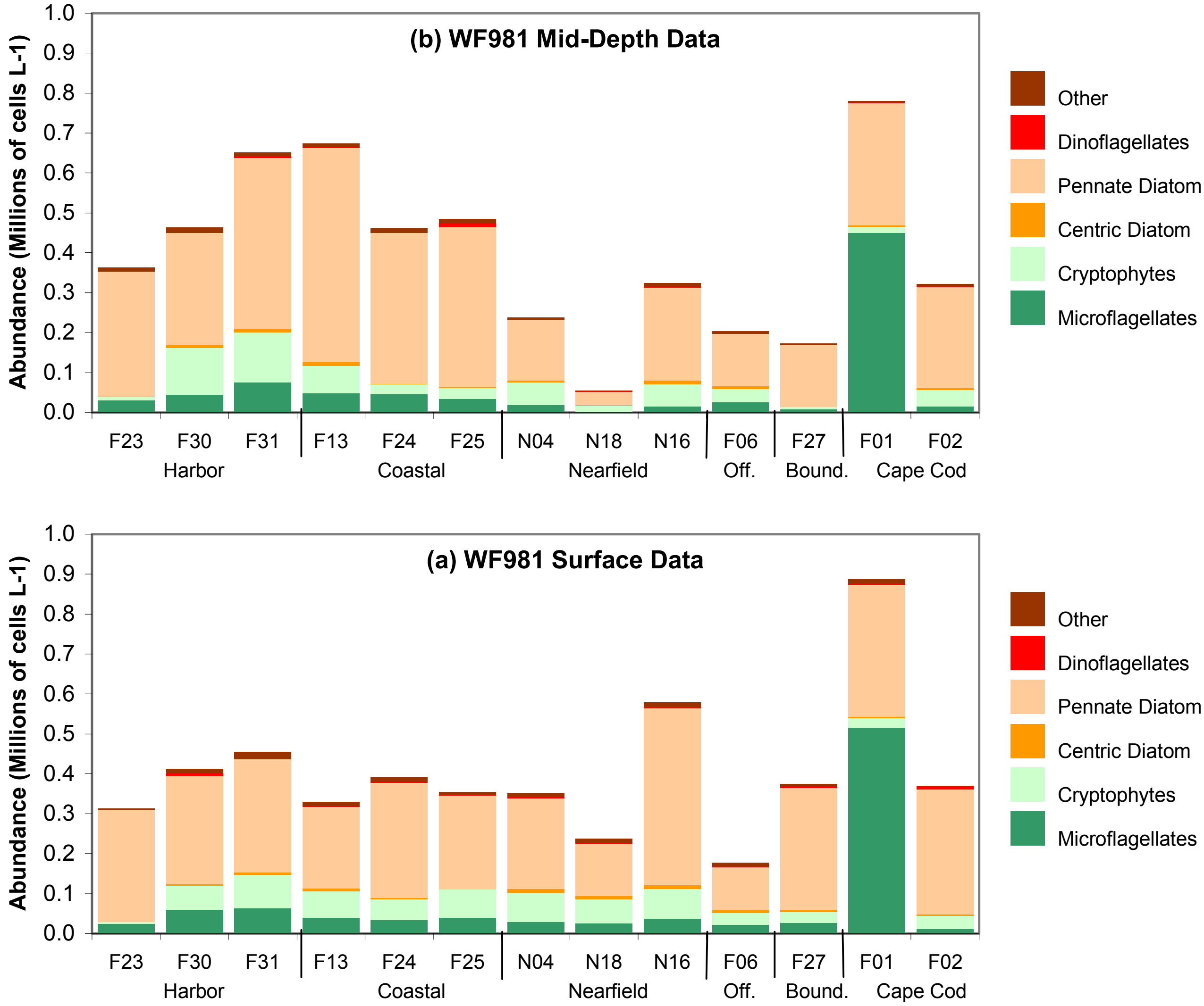
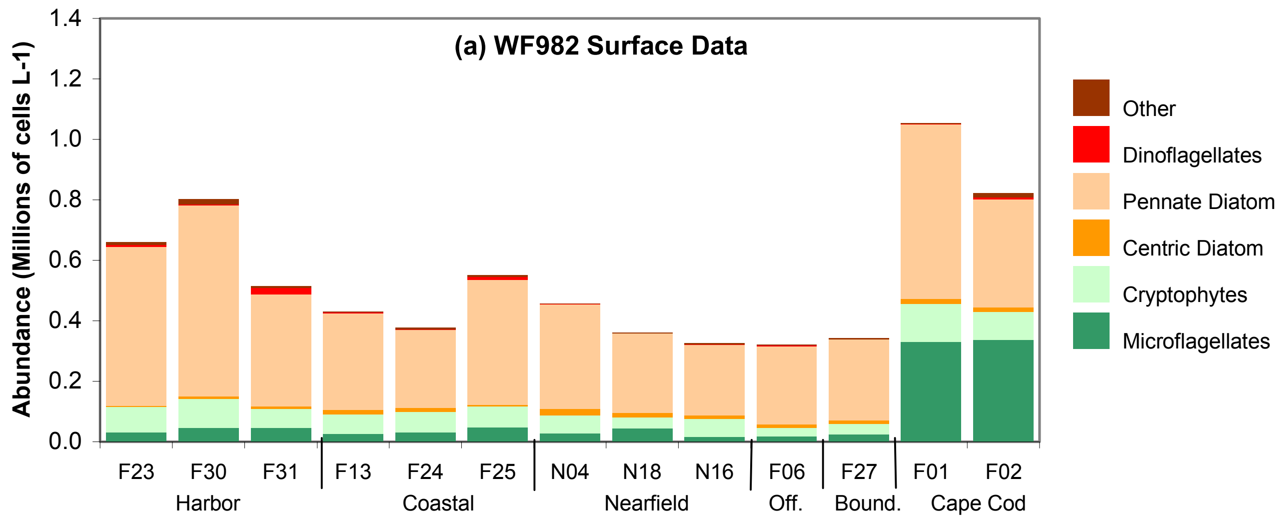


Figure 5-13. Phytoplankton Abundance By Major Taxonomic Group – WF981 Farfield Survey Results February 1 – 11, 1998



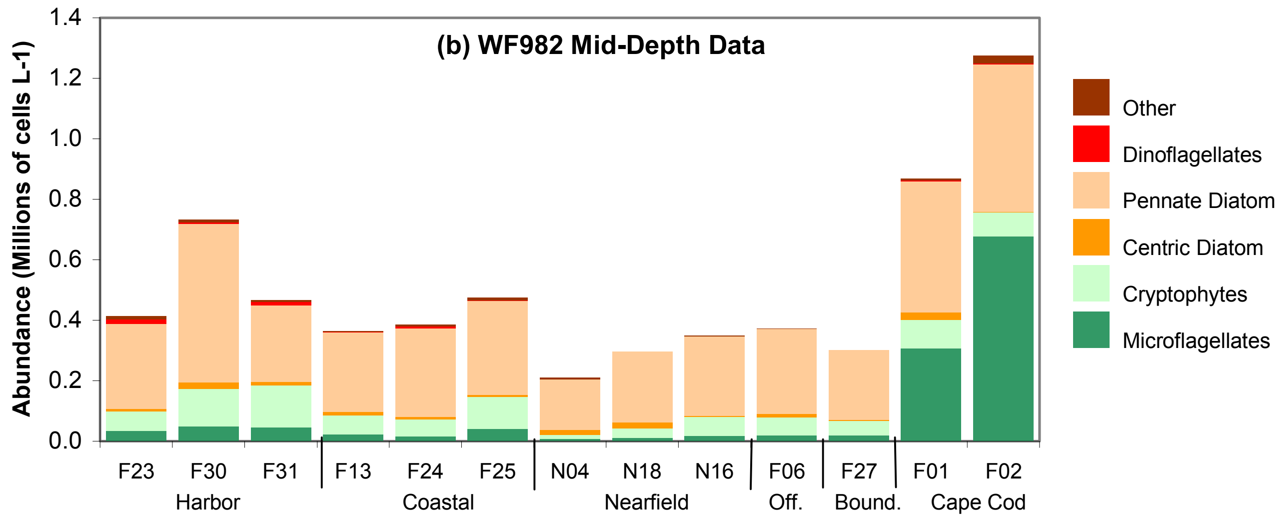


Figure 5-14. Phytoplankton Abundance By Major Taxonomic Group – WF982 Farfield Survey Results February 27 – March 2, 1998

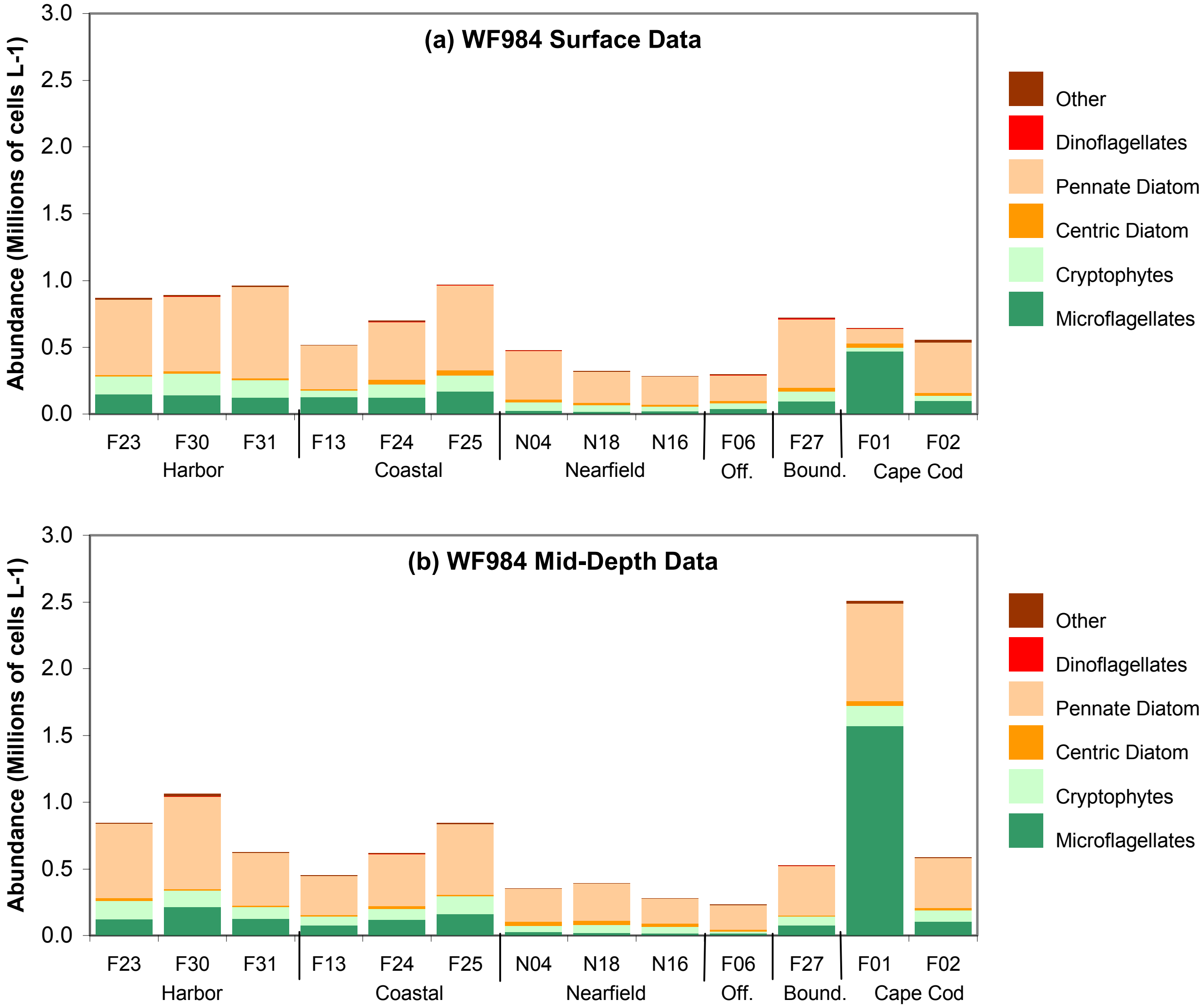
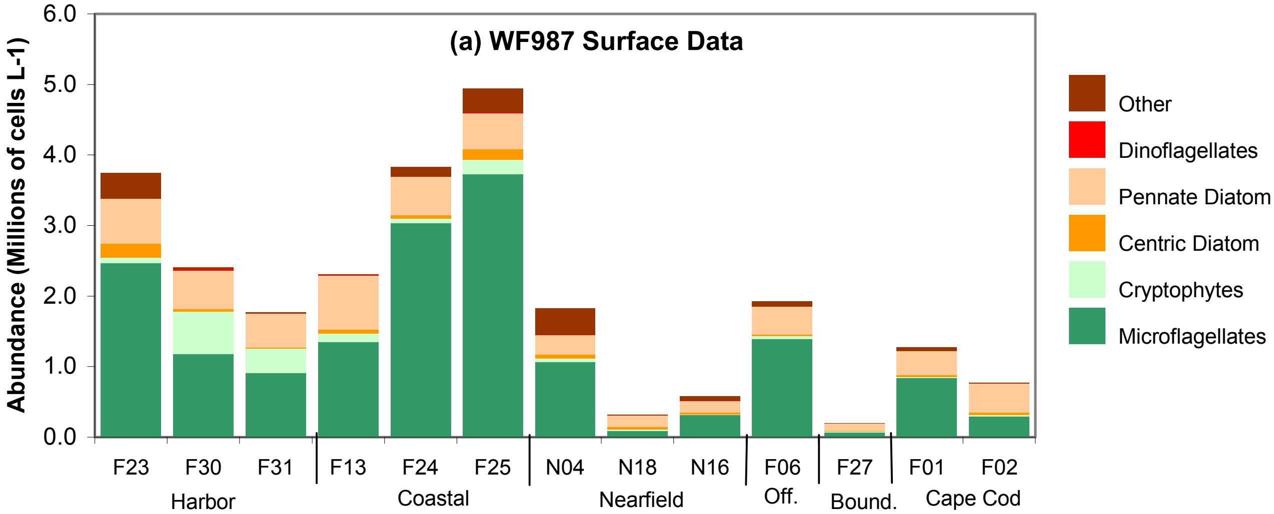


Figure 5-15. Phytoplankton Abundance By Major Taxonomic Group – WF984 Farfield Survey Results March 31 – April 3, 1998



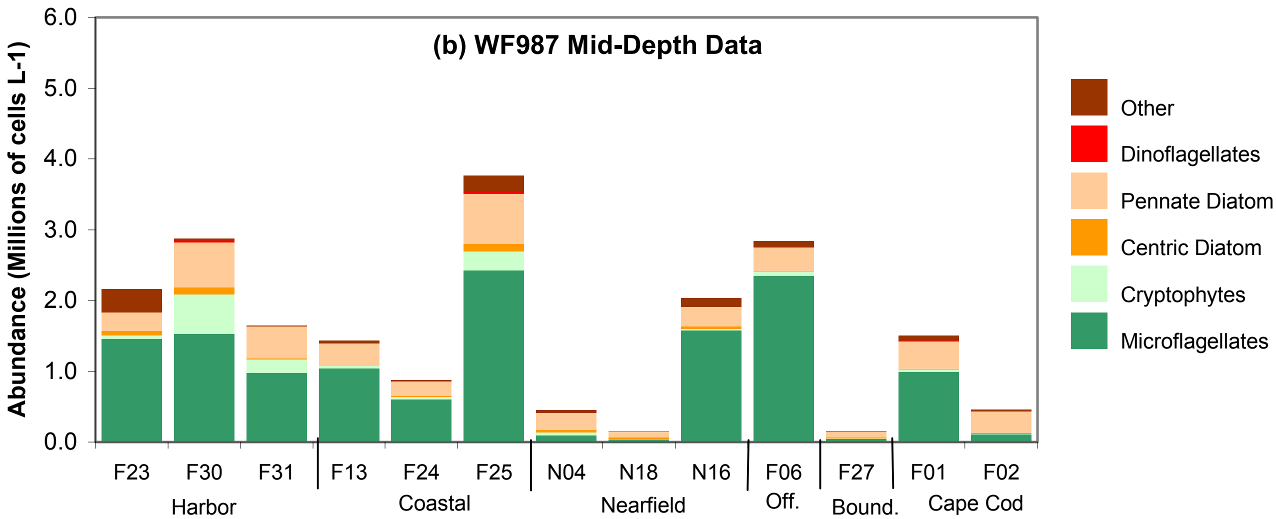


Figure 5-16. Phytoplankton Abundance By Major Taxonomic Group – WF987 Farfield Survey Results June 16 – 22, 1998

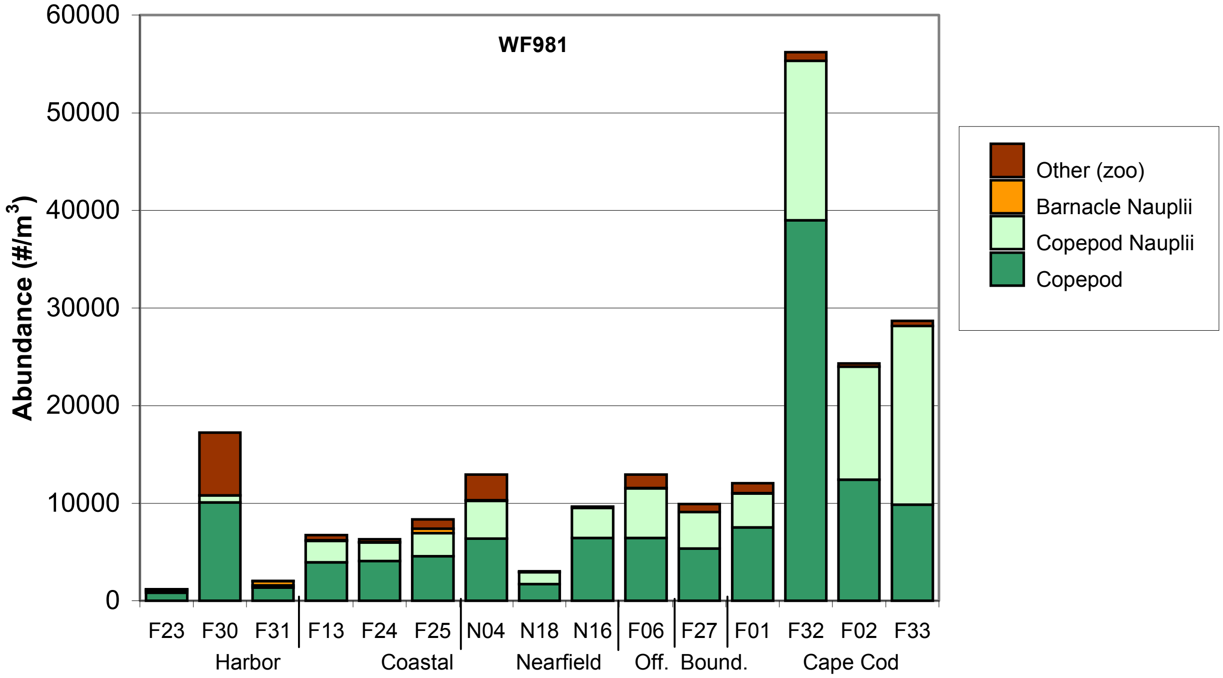


Figure 5-17. Zooplankton Abundance By Major Taxonomic Group – WF981 Farfield Survey Results February 1 – 11, 1998

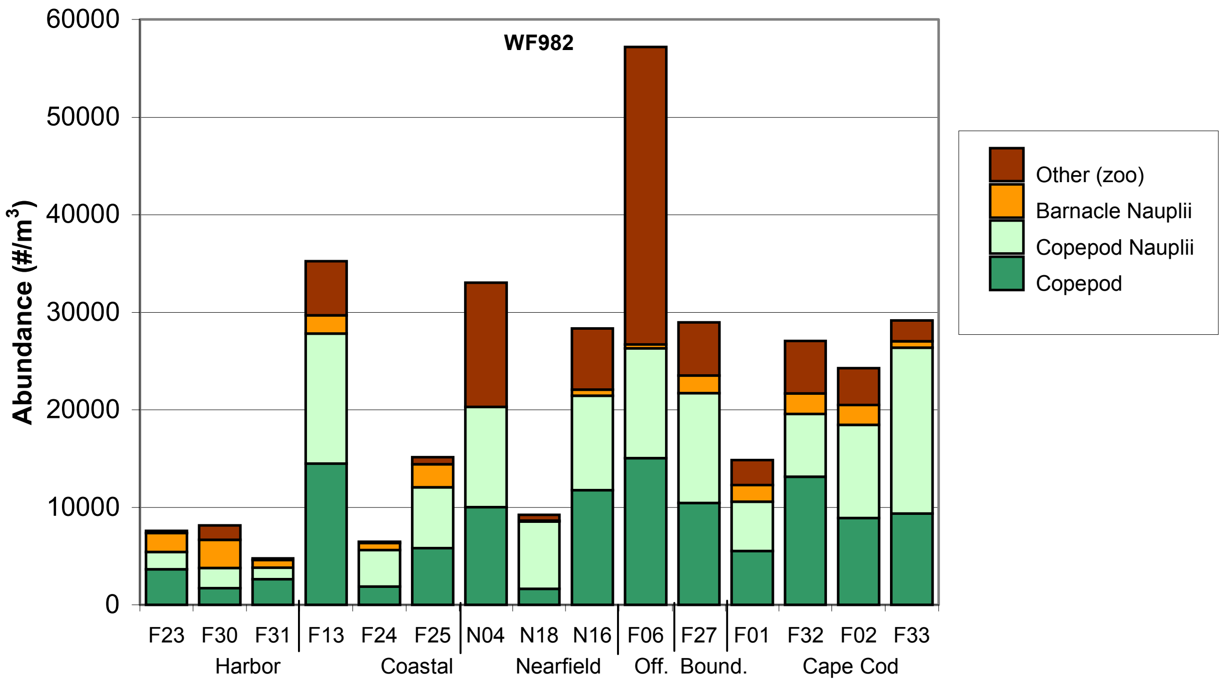


Figure 5-18. Zooplankton Abundance By Major Taxonomic Group – WF982 Farfield Survey Results February 27 – March 2, 1998

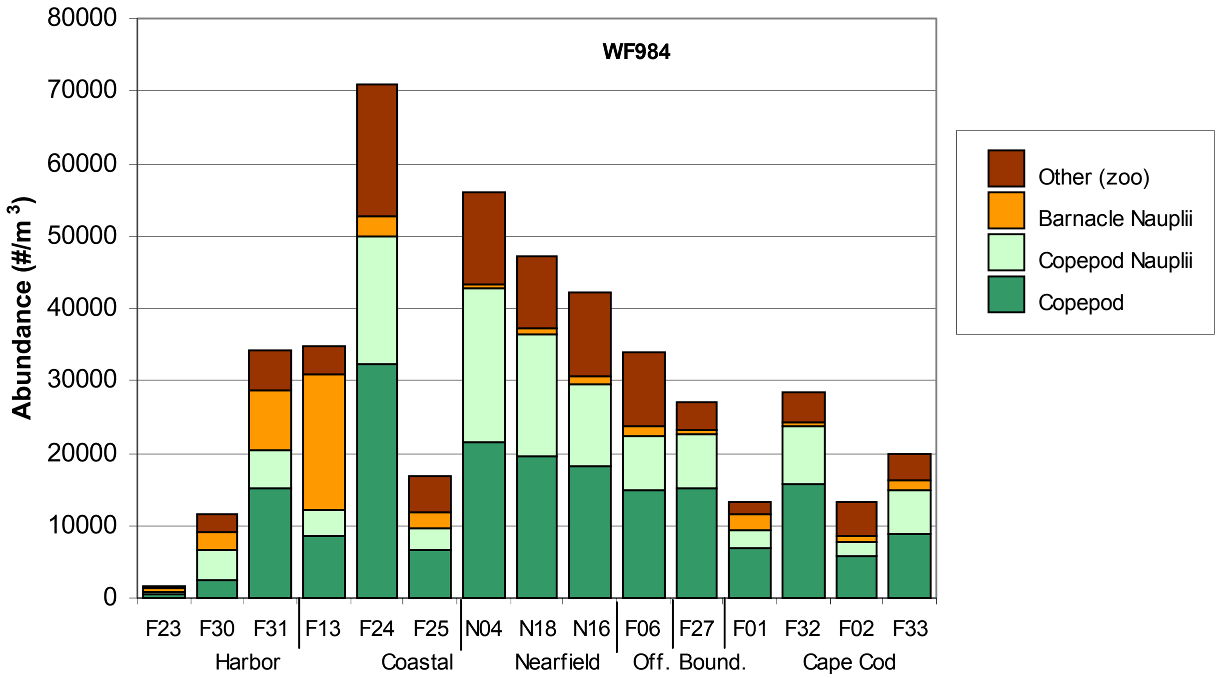


Figure 5-19. Zooplankton Abundance By Major Taxonomic Group – WF984 Farfield Survey Results March 31 – April 3, 1998

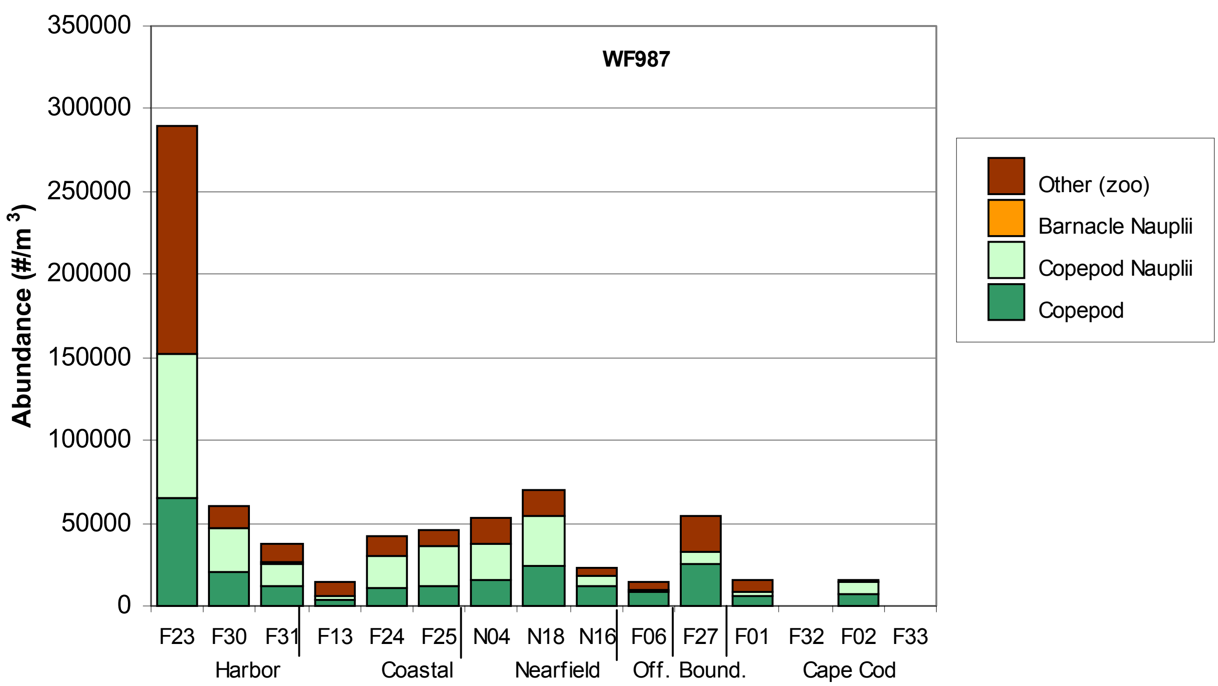


Figure 5-20. Zooplankton Abundance By Major Taxonomic Group – WF987 Farfield Survey Results June 16 – 22, 1998

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The winter to spring transition in Massachusetts and Cape Cod Bays is characterized by a typical series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. For the first half of 1998, however, conditions in the Bays were marked by the delayed onset of seasonal stratification, lack of a winter/spring phytoplankton bloom, and nutrient replete conditions. This section presents a summary of the integrated physical, biological, and chemical trends discussed in previous sections.

From February to March 1998, the water column was well mixed and relatively high concentrations of nutrients were measured. The availability of nutrients, however, did not result in elevated rates of biological production or a winter/spring phytoplankton bloom. Microflagellates and cryptomonads dominated the phytoplankton community and centric diatoms, which normally produce the winter/spring phytoplankton bloom, were only dominant at the Cape Cod Bay stations. Chlorophyll concentrations were low (0-2 μgL^{-1}) throughout the Bays and productivity was low both in the nearfield (<300 $mgCm^{-2} d^{-1}$) and Boston Harbor (100 $mgCm^{-2}d^{-1}$). Chlorophyll-specific production, however, was relatively high at each of the nearfield stations suggesting that nutrient conditions were not limiting productivity and that other processes (e.g. water column instability, predation by zooplankton or micrograzers) may have been limiting production. The lack of a winter/spring phytoplankton bloom in 1998 represents a major aberration in the seasonal productivity pattern relative to previous years for the nearfield region and will be investigated in more detail in the 1998 Annual Water Column Report.

By early April (WF984), chlorophyll concentrations had increased with high concentrations being observed for subsurface waters in Cape Cod Bay (17.0 μgL^{-1}) and the coastal area (15.3 μgL^{-1}). Microflagellates remained the dominant phytoplankton in Massachusetts Bay and had increased in abundance from the February surveys. Total phytoplankton abundance, however, was still relatively low (<10^6 $cellsL^{-1}$) at all but station F01 where elevated numbers of centric diatoms (and the high chlorophyll values) were observed. Dissolved inorganic nutrients were still present at non-limiting concentrations throughout most of the region. Productivity, however, was still low in the nearfield (<300 mg C m^{-2} d^{-1}) and Boston Harbor (125 $mgCm^{-2}d^{-1}$).

In early May (WN985), the water column in the nearfield was beginning to stratify and nutrient concentrations in the surface waters had decreased. Chlorophyll concentrations in the upper 20-m of the water column were low while the concentrations below the pycnocline ranged from 2-8 μgL^{-1}. The high productivity rates that were observed at these depths suggest that the increase in chlorophyll resulted from localized production that was coincident with elevated nutrient concentrations near the pycnocline. By the middle of May (WN986), stratified water column conditions were present across the nearfield. Coincident with the establishment of stratified conditions, chlorophyll concentration and areal production were at the highest values observed in the nearfield during the February to July reporting period. Chlorophyll concentrations were 14-33 μgL^{-1} over the upper 15-m of the water column at the near-harbor station N10 and values >14 μgL^{-1} were observed in a subsurface chlorophyll max layer along the entire nearfield transect. The distribution of chlorophyll suggested a harbor or coastal influence with productive phytoplankton and/or nutrients being transported offshore to the nearfield area. The increased production during the May surveys led to a decrease in nutrient concentrations across the nearfield (except for SiO_4).

A combination of physical and biological factors contributed to the extended period of replete nutrients in the spring of 1998. As mentioned above, seasonal stratification did not develop until May, thus for much of the spring the water column was well mixed supplying nutrients to the surface waters. Additionally, storms in late February may have contributed not only to the instability of the water column, but also to increased terrestrial runoff of nutrients into the bays. Finally, areal productivity was relatively low throughout the region, there was no winter/spring diatom bloom, and the abundance of phytoplankton remained < 10^6 $cellsL^{-1}$until May, thus biological nutrient uptake was relatively low. The combination of physical instability and biological inactivity resulted in elevated nutrient concentrations in the surface waters throughout most of the region.

Regionally, seasonal stratification was not observed until June (WF987). A significant rain event occurred prior to the June farfield/nearfield survey and, as a result of the rainfall and concomitant increase in runoff, low salinity surface waters were observed along the coast from Boston to Gloucester and into the northern and eastern portion of the nearfield. In these areas, the presence of low salinity surface waters served to intensify the already established water column stratification. Elevated SiO_4 concentrations were observed in the low salinity surface waters, but throughout the rest of the region dissolved inorganic nutrients were generally depleted. At Boston Harbor station F23, areal production reached a maximum value of 1,104 $mgCm^{-2}d^{-1}$ in June. Bottom water DO had increased between the April and June combined surveys. Normally, the DO concentrations decline in the bottom waters over this time period, but, consistent with the lack of a winter/spring phytoplankton bloom and the increased productivity observed during the WF987 survey, bottom water DO concentrations were higher throughout most of the farfield region in June.

During the July nearfield surveys, bottom water DO concentrations declined and more typical DO gradients were observed. Chlorophyll concentrations were relatively high in the upper 15 m of water leading to the higher surface water DO concentrations, though productivity was low during both July surveys (<200 $mgCm^{-2}d^{-1}$). The decrease in bottom water DO concentrations was coincident with an increase in respiration rates in July.

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